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# PRESIDENT'S MESSAGE

## Organization and Operation of the AIIE

By E. L. Slagle

*President, American Institute of Industrial Engineers, Inc.*

Since your interest in, and understanding of, the American Institute of Industrial Engineers provides the very foundation upon which our organization grows in stature and in strength, I believe that a description of the operations of the AIIE would be beneficial. What follows will be a compromise between the desire to provide you with a very comprehensive picture of our organization and the desire to keep the message reasonably short.

Our organization (shown on the accompanying chart) is, in some respects, comparable to that of a large corporation. The National Convention has certain aspects which could be compared with an annual meeting of stockholders. Our Board of Trustees functions like a Board of Directors. Our Executive Committee and the national officers perform in a manner similar to executive committees and officers found in industry.

There are, of course, some differences. The offices, except for the Executive Secretary and Assistant Executive Secretary, are elective positions in the AIIE. Our Executive Secretary serves, to some degree, like an administrative vice president. Another important difference is our breakdown into regional groups with each regional group being represented on the Board of Trustees by a Regional Vice President and represented at the National Convention by delegates, the Regional Vice President, and chapter representatives.

The AIIE committees are a line and staff arrangement. Some of these committees develop and recommend policies. Other committees and positions are responsible for implementing policies, procedures, and actions, as directed by the President.

### National Convention

First, let us review the part which the National Convention plays in the operation of our organization. The constitution requires that a National Convention be held once each year at a time and place designated by the Board of Trustees. You may be interested in knowing that local chapters desiring to host the National Convention must submit an invitation prior to thirty days before the annual convention. To provide sufficient time for the chapters to organize and develop this national meeting, the selection of the convention site is made by the Board of Trustees two years in advance.

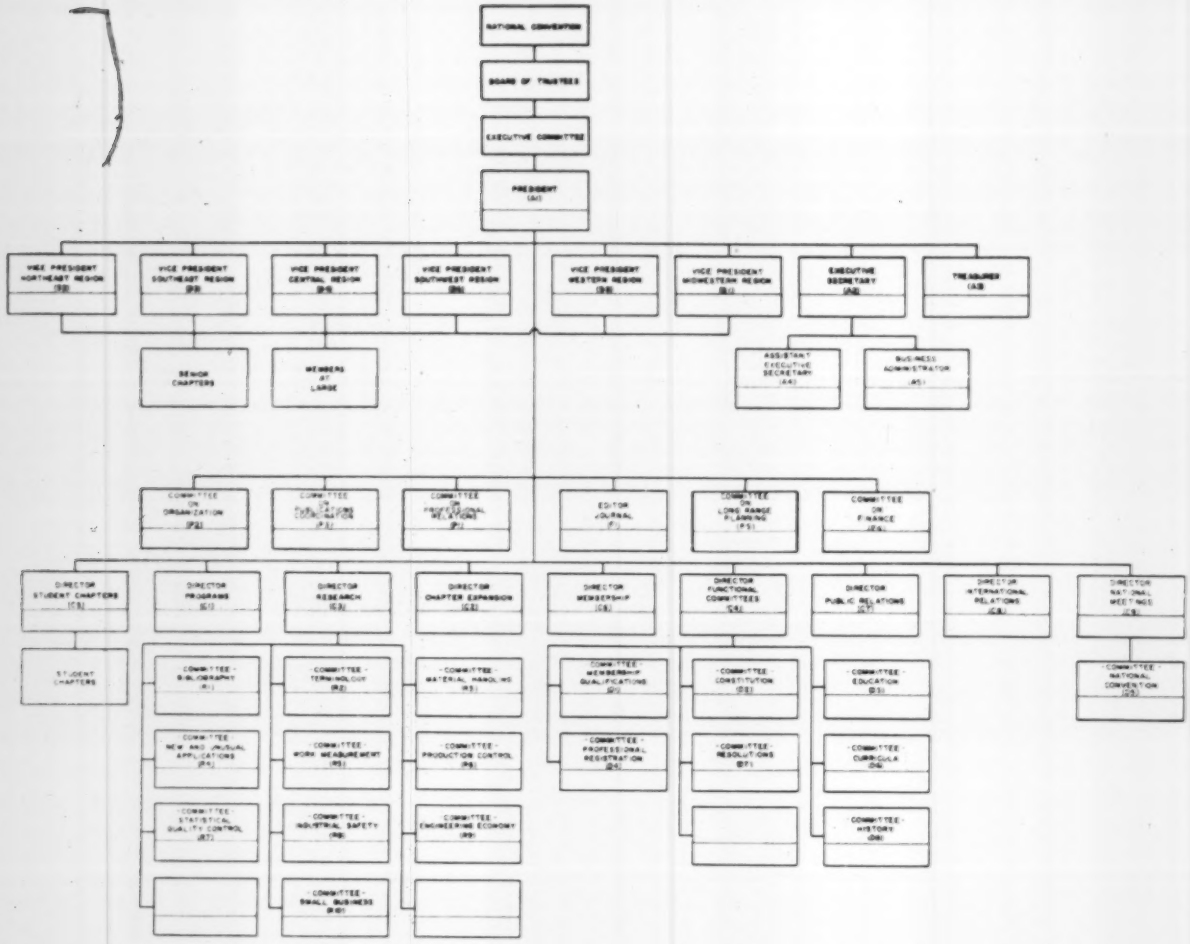
The National Convention is the legislative body of the AIIE, and the voting members of the convention consist of the national officers, the senior chapter delegates, and the delegates-at-large from each region.

Each senior chapter is permitted one voting delegate selected by the chapter. Delegates-at-large are appointed by the Regional Vice Presidents in the number of one delegate-at-large per 100 members, or fraction thereof, in the region. All delegates serve for a one year period and must be reported to the Executive Secretary no less than 30 days before the first day of the National Convention.

The constitution specifies that the President and the Regional Vice Presidents shall present an annual report of the past year's activities at the convention. It should

AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS

NATIONAL ORGANIZATION



be noted that the constitution specifies that each senior chapter president shall also make available a report on the activities of his chapter. Such reports are summarized and presented by the Regional Vice Presidents.

At the regular meeting of the National Convention, which normally convenes on a Saturday immediately following our national conference, the various annual reports are made and the more important problems of immediate concern are reviewed. It is at this meeting that your Board of Trustees and national officers obtain their best insight into the thinking and desires of the membership. Although there are many occasions for personal contacts, and although there is much correspondence during the year, the National Convention provides an excellent source of guidance and is a sounding board for proposed actions of the national organization.

Amendments to the constitution become effective with an affirmative vote of three-fourths of the delegates. These amendments must be proposed by written petition or proposed by the Board of Trustees. An amendment cannot be acted upon, however, unless a copy of the proposed amendment is sent to each regular member by the Executive Secretary at least sixty days before the National Convention. This period of time allows for proper consideration by the regions and chapters and for proper instruction of the delegates. It is of extreme importance that you remember to instruct your delegates properly and that you appoint delegates who will faithfully carry out the instructions of the appointing authority (a chapter or a Regional Vice President). In the past, frequent confusion, ill-considered actions, and costly delays have been occasioned by delegates present-

ing one point of view, although there was already in the national file a recent contradictory point of view expressed by the individual or body appointing the delegate in question.

Special meetings of the National Convention may be called by a majority vote of the Board of Trustees whenever such action must be taken in the best interests of the AIIE.

**Board of Trustees**

The constitution provides that the Board of Trustees shall exercise the powers of the National Convention in the interim between conventions, subject to such restrictions as may be imposed by the provisions of the constitution. The members of this board are: the President, the Executive Secretary, the Assistant Executive Secretary, Board Members-at-Large, and the Regional Vice Presidents. The bylaws provide that the Board shall meet at least once per year. In actual practice the Board convenes in October and at the time of the National Convention.

The Board of Trustees is empowered by the constitution to assign additional duties to the national officers; to charge national dues; to pass, repeal, or modify bylaws pertaining to matters not expressly specified in the constitution; to specify regions and the number of Vice Presidents; to grant charters to new chapters; to approve or disapprove amendments to chapter constitutions and changes to chapter bylaws, and to delegate responsibilities and duties to the Executive Committee. The Board of Trustees has as its chairman the President of the AIIE.

**Executive Committee**

The President, the Executive Secretary, the Assistant Executive Secretary, the Treasurer, and the immediate past President constitute the members of the Executive Committee.

The duties and powers of the Executive Committee are those delegated by the Board of Trustees. Meetings are normally held once a month at Columbus, Ohio, to review problems which have arisen during the month, to provide necessary guidance to the President, and to prepare recommendations with regard to changes in policy and bylaws for action by the Board of Trustees.

**National Officers**

The national officers of the AIIE are the President, Executive Secretary, Assistant Executive Secretary Treasurer, Board Members-at-Large, and the Vice Presidents from each region. All officers are elected for one-year terms, except for the Board Members-at-Large who serve for two years to provide greater continuity of experience and to facilitate the transfer of current business from the retiring to the incoming slate of officers. The positions of Executive Secretary and Assistant Executive Secretary are filled by appointment by the Board of Trustees. Only fellows and senior members are eligible for nomination to the national offices.

National elections are held once each year, normally during the month of March. The entire membership participates in the voting for the positions of President, Board Members-at-Large, and Treasurer. Vice Presidents, of course, are elected by the vote of only the members of the region which they serve. A nominating committee, comprising the Regional Vice Presidents, prepares a slate of nominees for the positions of President, Treasurer, and Board Members-at-Large. This slate of officers is forwarded to the Executive Secretary in February. Similarly, regional nominating committees, comprising the Regional Vice President, the chapter Presidents, and the Delegates-at-Large, prepare a nominating slate covering the position of Vice President of the region concerned. The nominating ballots are reviewed at the national headquarters by the Executive Secretary and a Teller's Committee appointed by the President. Following this review, the national ballot is prepared and mailed to the membership.

In addition to serving as Chairman of the Board of Trustees and the Executive Committee, the President takes the necessary action to implement the decisions and policies of these governing groups, appoints committees and defines the functions thereof, and, in general, directs the operation of the organization within the limitations imposed upon him by the governing groups.

The Treasurer prepares monthly cost statements, providing the Executive Committee with the necessary information with regard to income and expenses, and makes the necessary comparison statements of actuals against budgets. In addition to this, the Treasurer is required by the constitution to prepare and to present at the National Convention an up-to-date financial statement covering the period of his term of office and to report periodically to the Board of Trustees the financial condition of the organization.

It is the responsibility of the Executive Secretary and the Assistant Executive Secretary to operate the national headquarters on a day-to-day basis. The volume of work involved in routing inquiries to the proper committees, answering letters, and preparing reports has grown to such a point that it is necessary to maintain at the national headquarters in Columbus a full-time business administrator and full-time stenographic help. This office force assists the Executive Secretary in the discharge of his duties.

I am frequently asked questions with regard to financial assistance to the national officers by the AIIE. All officers serve without salary. At this time, it is not the policy of our group to pay for travel and other expenses incurred by the national officers in connection with attendance at the National Convention, Board of Trustees meetings, Executive Committee meetings, committee meetings, and meetings of other professional and national groups at which we have representation. There have been a very few situations in which some portion of the expenses of a national officer have been borne by the national treasury.

## Other National Officers

The national officers of the AIIE who direct and represent the regions are the six Regional Vice Presidents. The six regions are the Northeastern, Southeastern, Central, Midwestern, Southwestern, and Western.

The constitution requires that the Vice Presidents shall supervise the chapters in their respective regions and shall arrange for regional conferences as described in the bylaws. Each Vice President is also required to follow the activities of the chapters in his region and to prepare an annual report for presentation at the National Convention.

The Regional Vice Presidents cooperate with educational institutions in their respective regions, encourage chapter organization, arrange to invite members-at-large to regional conferences, appoint delegates-at-large for the region, and conduct nominations for their successors.

The Vice Presidents perform a very necessary function in coordinating AIIE activities in their respective areas and in providing representation for their local chapters and their region at the meetings of the Board of Trustees.

## Committees

The committees of our national organization may be categorized as functional, technical, and special. Certain of these committees are also designated as standing committees by the constitution or bylaws because of their importance to the organization.

Committees other than the standing committees may be established by a motion and majority vote of the membership at the National Convention, by the vote of the Board of Trustees, or by the Executive Committee. Committees may also be initiated by the President.

Committee chairmen are appointed by the President and shall perform such duties as may be assigned by him. To the degree possible, of course, the President consults with other national officers prior to the appointment of a national committee chairman. The term of the appointment is normally one year. Committee members, unlike elected officers, may, and frequently do, serve for several successive years on the same committee.

Committees may be established to perform specific tasks related to the functioning of the organization, or to investigate any subject within the scope of the areas of interest of the Institute and the profession. Each committee is expected to prepare an annual report of its activities. All committee reports and publications become the property of the Institute.

Because of the large number of committees it has become necessary to coordinate committee activity in order to provide staff assistance to the President in directing the activities of the committees, and also to provide the committees with a greater degree of stability during the period when the newly elected officers and newly appointed committee members are getting their feet on the ground. The Board of Trustees, therefore, voted at their May 1, 1953, meeting to empower the President to appoint, subject to Executive Committee approval, a number of directors to coordinate and administer certain functions for the President. The term of appointment of a director is one year, beginning October 1 of each year. Since the term of appointment overlaps that of the regular term of officers, greater organizational stability is provided. At the present time, we have nine such directors.

The Director of Programs coordinates all activities related to the formation of programs. During the past year, the chief objective of our Director of Programs was the development of a manual for use by the chapter Program Committee chairmen. This manual contains information concerning such matters as: planning the program, sources of speakers, courtesies to speakers, substitute speakers, topic listings, and available speakers.

The Director of Chapter Expansion is responsible for the coordination of all activities in connection with the formation of new chapters. During the past year a manual "How to Start a Chapter of the AIIE" was developed. This manual is proving to be of material assistance in the formation of new chapters.

The Director of Student Chapters is responsible for:

1. Fostering the establishment of new student chapters;
2. Encouraging the growth of existing chapters;
3. Improving the relationship between student chapters and senior chapters;
4. Providing incentives for students to develop a true professional attitude through student contests, awards, and other chapter activities;
5. Coordinating actions designed to encourage students to enter the profession of industrial engineering; and
6. Obtaining the maximum conversion of student members to associate members following graduation.

The Director of Membership is responsible for developing programs to increase the membership growth rate. This director must work closely with the Membership Qualifications Committee since it is not the desire of the Institute to compromise in any way our membership standards. Through the activities of your own chapter membership committee, I am sure that you are all acquainted with the national efforts in this direction. This year, we are publishing a manual "How to Insure AIIE Membership Growth".

It is the function of our Director of Public Relations to coordinate all committee work related to the furtherance of public knowledge, and acceptance, of industrial engineering. We must not fail to recognize that industrial engineering is one of the newest and, perhaps, least-known branches of engineering. Consequently, it is most misunderstood. A comprehensive study of the problem has been completed.

Our Director of International Relations is responsible for developing and maintaining a working relationship with industrial engineers and professional engineering and management groups in other countries.

Our Director of National Meetings has the responsibility of developing policy and procedure regulating all national meetings. The number of such meetings is increasing every year. It follows that some policy control is required to avoid the failures which would result from lack of experience, scheduling conflicts, programs not in keeping with the interests of the Institute, and failure of the national organization to provide the means whereby the knowledge gained by one group may be passed on to another.

The Director of Functional Committees coordinates the work of eight national committees.

1. The Membership Qualifications Committee reviews and verifies all data contained in submitted applications and confers or withholds membership. Findings of the Committee are subject to review by the Board of Trustees. Because of its importance in upholding the standards of membership in the Institute, this committee has been designated as a standing committee in the bylaws. Over 100 applications are processed nearly every month by this group. I believe that you will agree that each application should be given a very thorough inspection in all fairness to the member and to the Institute. The national headquarters office receives many complaints with regard to the delay in processing applications. The Membership Qualifications Committee invites constructive suggestions to eliminate the problem, and has recommended that the complainants be appointed to serve on the committee.

2. A Constitution Committee prepares changes to the constitution and bylaws as recommended by the President, the Board of Trustees, the National Convention, or by petition of ten or more regular members of the Institute. Independent studies are conducted for the purpose of maintaining the constitution and bylaws in such form as to best serve the Institute in the attainment of its objectives, protecting the rights and interests of the members, and providing the officers with proper powers and procedures to expeditiously conduct the affairs of the organization.

3. The Education Committee, another standing committee, collects and disseminates information for use by students and other individuals interested in the educational opportunities in the field of industrial engineering. The committee reviews problems having their origin in college and university curricula.

4. The Professional Registration Committee actively encourages industrial engineers to register. The committee assists members of the organization with regard to registration problems and assists chapters attempting to effect changes in State registration laws. One objective of this committee is the attainment of recognition of the industrial engineers by the various State Boards of Engineering Registration.

5. The Convention Committee is responsible for all arrangements and programs in connection with the national conference and convention.

6. The Curricula Committee reviews industry requirements and assists engineering schools and colleges desiring help in development of industrial engineering programs of study for graduate and undergraduate.

7. The Resolutions and Awards Committee is responsible for encouraging activity by both individuals and chapters. This committee recommends recognition and other awards. A formalized program designed to meet the objectives of this committee is being developed.

8. The History Committee, through review of the records of the AIIE, is developing a history of our organization. Once the history is recorded to a current date, future activities of the committee will be to maintain this information on a current basis.

The Director of Research is responsible for coordinating the activities of the various research committees. These committees are: Bibliography, Terminology, Material Handling, New and Unusual, Work Measurement, Production Control, Statistical Quality, Industrial Safety, Engineering Economy, and Small Business. It is the objective of this group to foster and encourage research in the field of industrial engineering. It is not the objective of this group to engage in research.

Other committees have been appointed for special purposes.

The Committee on Professional Relations was established to work with other professional groups and explore the possibilities of affiliation with these groups. The work of this committee has resulted in our gaining associate membership for the AIIE on the Engineers' Joint Council. This was the first step in the direction of aligning the industrial engineer with his colleagues in other branches of the ever-widening field of engineering. Currently, discussions are being held with the Engineers' Council for Professional Development. It is the official position of the AIIE that we should share the burden of accrediting curricula related to the field of industrial engineering. The E.C.P.D. has accepted this point of view and we currently have 24 top-ranking industrial engineers on the E.C.P.D. accrediting team. In addition to this, the AIIE has been invited to work on an E.C.P.D. committee designed to develop the industrial engineer during the first five years following graduation.

The Committee on Organization develops and maintains job descriptions for all officers and national committee chairmen. This committee also has the responsibility for the organization chart and manual, and makes recommendations to the President with regard to changes in the organization and job duties.

The Committee on Publications Coordination and Plans is responsible for policy and procedure pertaining to all publications of our organization.

I hope that this brief review of the organization and operation of your AIIE will be of assistance and provide you with at least some of the vital background information required for intelligent consideration of the various problems and actions of our Institute.

# Performance Sampling in Work Measurement

**By Ralph M. Barnes and Robert B. Andrews**

*University of California, Los Angeles*

In 1935 L. H. C. Tippett described a statistical method which he had developed in the English textile industry to measure operator and machine delays (26). R. L. Morrow (18) was one of the first people in this country to use Tippett's methods and this technique has come to be known as the Ratio-Delay method.

In 1940 we started our statistical studies of work measurement, and a summary of some of our findings was published in 1950. That report (11) presented evidence as to the reliability, validity, and practicability of the ratio-delay method as applied to manufacturing operations in this country. Over the years the ratio-delay method has found increasing use, and numerous articles have been published describing applications of this technique.

From the outset we believed that sampling could be used to measure work and some people have used sampling for this purpose. However, it appears that few studies have been made of the type of statistical distribution which is representative of performance levels of manually paced operations, nor has a specific statistical technique been developed based upon the appropriate distribution and which is applicable to work measurement. This report contains the results of several studies of ours pertaining to performance sampling for work measurement, including a comparison of performance sampling and time study as means of measuring industrial operations.

In this report we are using work sampling as the broad term which includes results obtained from performance sampling and also from the application of the ratio-delay method. Performance sampling is the name we have given to the sampling procedure for obtaining the average performance index of the operator's productive activities during the working day. Whereas ratio-delay is the name of the sampling method used to determine the part of the work day (number of minutes) during which the operator is working productively and the part of the day during which he is idle. Ratio-delay studies also make it possible to obtain a breakdown of the reasons for the delays or idle time.

### *Conclusions*

Our studies seem to indicate that work sampling will give time standards for repetitive standardized manual tasks which are substantially the same as standards obtained by time study. Moreover, sampling measurements can be made with a pre-assigned reliability. Even in a plant where methods are not standardized and where job descriptions are nonexistent a performance index by operator or by department can be obtained by work sampling. Such data would show the standard hours of productive work, average performance index, idle time and delays, and a breakdown of the various reasons for the nonproductive time.

We believe that work sampling provides a valuable tool for measuring work, and that this simple inexpensive method will find wide use in many areas where manual work is performed.

### *Acknowledgments*

The authors want to express their sincere appreciation to all those who participated in this study. Special thanks are due E. S. Buffa, Donald C. Demangate, J. A. Gary, Professor E. P. Coleman and Professor Paul G. Hoel who assisted with various phases of this investigation. We are also greatly indebted to the organizations that so generously participated in the validation study and whose identity we agreed not to reveal.

## Objective

This project was undertaken to develop a sampling technique which would provide an accurate and economical method of determining, with a pre-assigned reliability, the performance level of labor activities. The technique was to be applicable to any well defined physical task.

## Scope of the Investigation

The study of the applicability of statistical sampling methods to work measurement was divided into three main phases:

1. The investigation of the type of statistical distribution which is representative of performance levels of manually paced operations.
2. The development of a specific statistical technique based upon the appropriate distribution and applicable to work measurement.
3. The testing of the validity of the proposed statistical method by studies actually carried on in industrial organizations.

## Phase 1—Analysis of the Statistical Distribution

An investigation was made to determine the nature of the distribution which was representative of performance indices. The procedure employed was to obtain actual data from the random observation of workers' performance

levels over a period of time. The necessary data were obtained through the cooperation of two manufacturing organizations. In both instances the operations examined were completely manually controlled by the operators. A total of over 8000 random observations were taken.

The next step was the analysis of the data to determine what generalizations could be made about the theoretical parent populations. The hypotheses that the populations were normally distributed were tested. The Chi-squared Test used to test these hypotheses resulted in a strong rejection of the hypothesis of normality for both sets of data. The probability that the sample data of either company was drawn from a normally distributed population was less than 1 in 10,000.

With the rejection of the hypotheses of normality, it was decided that no generalizations would be made about the distribution of performance indices. A complete report of this phase of the study has been published (4).

### Phase 2 Statistical Theory Applicable to Performance Sampling

Because of the results obtained in Phase 1, non-parametric statistical methods, which require no assumptions about the form of the distribution, were used to derive the relationships applicable to performance sampling. The basic equation governing performance sampling of work was determined to be $n_m = \frac{\sigma^2}{d^2\alpha}$. In this equation $n_m$ is the number of observations of performance levels in the sample, $\sigma$ is the standard deviation of the performance level population, $d$ is the difference between the population mean and sample mean and $\alpha$ is the level of significance. The complete derivation of this basic relationship has been published (5).

This equation permits one to determine the sample size required to give a desired maximum difference between the sample mean and the population mean for any specified level of significance. The solution of the equation to find an approximate sample size requires enough of a knowledge about the population to estimate its standard deviation. Tchebycheff's Inequality permits the determination of the extent to which the mean and standard deviation characterize the distribution when the mathematical form of the distribution function is not known. This theorem states that less than $1/k^2$ of the area of the distribution curve lies farther from the population mean than $k\sigma$.

Examinations of performance index distributions indicate that, for most operations and operators, the population standard deviation usually does not exceed a value of 12. Applying Tchebycheff's Inequality and assuming the mean actual performance index to be 125, a standard deviation of 12 will result in a distribution in which approximately 90% $(1 - 1/k^2 = 1 - 1/(3)^2)$ of the indices fall within the three standard deviation range about the mean or between 89 and 161. Under these assumptions the number of observations required to determine the

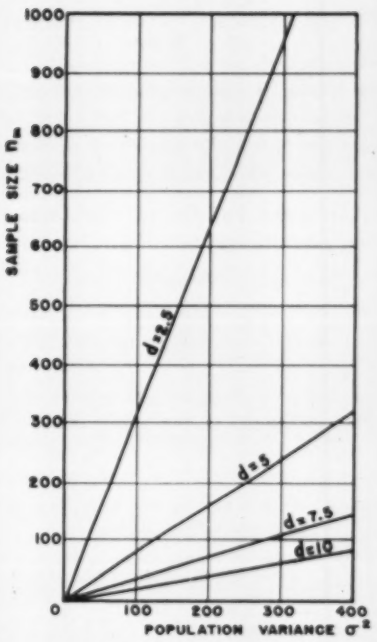



FIG. 1. Solutions of the Equation $n_m = \frac{\sigma^2}{d^2\alpha}$, $\alpha = .05$

average productive level to within $\pm 5$ units and with 0.95 confidence would be,

$$n_m = \frac{\sigma^2}{d^2\alpha} = \frac{(12)^2}{(5)^2(0.05)} = 115$$

Figure 1 presents graphically the relationship between sample size and population variance for the 0.05 level of significance and various desired maximum deviations between sample and population means.

The sufficiency of a sample, whose size has been based upon an estimate of $\sigma$, should be tested. This can be done by comparing the upper confidence limit of the population standard deviation with its assumed value. If the upper confidence limit is less than the estimated value, the sample size was adequate for the desired accuracy and statistical confidence. If, however, it is greater than assumed, additional sampling is required. This process of sampling and comparison must be repeated until the upper confidence limit is less than the assumed population standard deviation. The upper confidence limit is given by $s + \frac{cs}{\sqrt{2n_m\alpha}}$ where $\alpha$ and $n_m$ have the same definitions as given above, $s$ is the sample standard deviation and $c = \left[1 + \frac{\beta - 3}{2}\right]^{\frac{1}{2}}$. $\beta$ in this equation is the relative kurtosis as given by $\pi_4/\sigma^4$, the ratio between the fourth moment about the mean and the variance squared. The development of the equation for the upper control limit is also given in the Appendix.

By substituting $s$, the sample estimate of $\sigma$ for $\sigma$, and

solving for $d$, the form $d = \frac{s}{\sqrt{n_m \alpha}}$ is obtained. In this form, the reliability of a sample estimate of the population mean can be found. It also permits the determination of the $1 - \alpha$ confidence interval for the population mean. If $\bar{x}$ is the sample mean, the interval $\bar{x} \pm d$ will contain the population mean with a confidence coefficient of $1 - \alpha$.

### Phase 3—Test of the Validity of Work Measurement by Performance Sampling

*Procedure*

To validate performance sampling as a method of measuring work, it would be desirable to compare its results with other accepted methods of measuring work. Since time study is the most widely used method, performance sampling was tested against time study. The procedure for evaluating the proposed technique was a comparison of the normal time established by performance sampling, for each selected operation studied, with its corresponding normal time obtained by time study.

The necessary data were obtained under actual factory conditions through the cooperation of several industrial organizations. The actual studies were made by experienced industrial engineers of the cooperating firms. The studies which the participating companies were asked to make consisted of four main parts:

1. The selection of the operation to be studied.
2. The definition of the elements of the selected operation which were to be measured and the establishment of a normal time for the defined operation.
3. The taking of a random sample of:
   a. The productive effort applied to the measured work elements.
   b. The machine-controlled portion of the operation.
   c. The unmeasured work.
   d. The delays, personal, unavoidable, and avoidable.
4. The compilation of additional necessary information, including:
   a. The actual total time spent by each operator in the experimental group during the period of the study.
   b. The total number of units of work produced by each operator in the experimental group during the period of the study.

The selection of the operation to be studied was based upon certain definite requirements:

1. The operation must have had a standardized method.
2. The operators must have been experienced in the particular operation and have been following the prescribed method.
3. An additional restriction was placed upon operations which were partially machine controlled. The machine-controlled portion must have constituted from 15 to 85% of the total normal cycle time. To attain the desired accuracy with the desired statistical confidence, machine-controlled portions outside these limits would have required a prohibitively large sample size.

Once the operation to be studied had been selected, it was necessary to clearly define the elements to be included in the measured work category. In general, the criterion used for making this decision was the frequency of occurrence of each element. Those elements which occurred at least once each cycle were measured. Less frequent elements such as inspection, recording production counts, lining trays, etc., were classified as unmeasured work.

Since only experienced industrial engineers were utilized, the exact method of conducting the time study was left to the individual preference of the engineer. It was suggested that it be conducted according to the procedure regularly employed in the particular plant. It was considered essential that the same engineer make both the time study and the performance sampling study. This precaution eliminated one source of possible error—differences between raters in their concept of normal performance.

Another possible source of error was eliminated by restricting the validation procedure to only the measured portion of the total actual working time. Thus the comparison was made between the normal times established by performance sampling and by time study. Allowances were not included in the time study and, except for their use in ratio-delay analysis, personal, unavoidable and avoidable delays were excluded from performance sampling. This made it necessary to insure that a sufficient number of observations were taken to permit ratio-delay analyses to be made with the desired confidence. The number of observations necessary to determine the percent of the total actual time spent on measured work, within the desired accuracy, exceeded that required for performance sampling. Hence, the ratio-delay requirement was the determining factor in choosing the required sample size. A sample size of 600 observations was decided upon as a compromise between sample reliability and minimizing the demands upon the company. This sample size, with 95% confidence, resulted in absolute errors of ±2.4% and ±3.2% in the percent of actual time spent on measured work when the delays and unmeasured work totalled 10% and 20% respectively of the actual time.[1]

The number of operators, individually measured and simultaneously performing the selected operation, determined the number of sampling trips required to give a

[1] The required sample size was based upon the assumption that the delays and unmeasured work would constitute 10% of the actual time. The desired absolute error in the percent of actual time spent on measured work, with 95% confidence, was set at ±2.4%. The sample size necessary to yield these results was determined from the equation $n = \frac{(1.96)^2 p_m(1 - p_m)}{(e)^2}$, where $n$ is the number of observations, $p_m$ is the percent of actual time spent on measured work, and $e$ is the absolute sampling error in $p_m$. Substituting, $n = \frac{(1.96)^2(0.10)(1 - 0.10)}{(0.025)^2} = 554$. The required sample size was rounded off to 600 observations. The absolute sampling errors associated with total delays and unmeasured work of 10% and 20% were determined by substituting these values into the equation $e = \pm 1.96 \sqrt{\frac{p_m(1 - p_m)}{n}}$.

total of 600 observations. For example, if there were five operators, 120 ($5 \times 120 = 600$) sampling trips would be required. Once the number of trips had been established, the trip times themselves could be determined. The method used to select the sampling times was exceedingly important. Estimations of sampling errors are dependent upon a knowledge of the probability with which individual observations would be included in a sample. By simple random sampling, all possible combinations of observations, comprising a sample of a given size, will have equal probabilities of being selected. Trip times were randomized to maintain statistical validity.

The procedure used in making the actual performance sampling was as follows:

1. Observations were made of each operator in the experimental group at the selected times.
2. At the instance that the observer viewed each operator, the state of the operation was noted.
   a. If the element observed was classified as measured work, the operator was rated and his performance level was recorded.
   b. If the operation was in a delay or unmeasured work state it so was recorded.

The engineer making the study was supplied with written procedural instructions which included a table of random sampling times. Performance sampling data sheets were also provided.

*Results*

The results of the studies made are summarized in Table 1. The following guide to the chart explains each column. The illustrative figures are those actually used in computing the various quantities for the Company A study, line 1 of the Table. For those interested in following through the calculations associated with performance sampling, the complete computation procedure used to analyze the Company A Full Study is given. A sample of the original data sheets of the Company A Study is reproduced.

As an illustration of the results which would have been obtained if smaller size samples had been taken, Table 1 includes the results of 50% and 25% sub-samples of each full study. These sub-samples were obtained by systematic sampling of the original observations of each study. The systematic sampling plan for taking the 50% sub-sample consisted of selecting at random either 1 or 2 as the starting point and taking every second observation thereafter in the chronological order in which observations were originally taken. Similarly for the 25% sub-sample, every fourth observation, after a random starting point, was included in the sample.

Figure 2 shows the percent difference between normal time obtained by performance sampling and normal time obtained from time study for each of the fourteen different industrial operations studied. The average difference is 2.5% with maximum variations of +15.5% for Study No. F-2 and −6.2% for Study C-4.

FIG. 2. Results of Full Studies

Percent difference between normal time—performance sampling and normal time—time study.

FIG. 3. Results of 50 Percent Sub-Samples

Percent difference between normal time—performance sampling and normal time—time study.

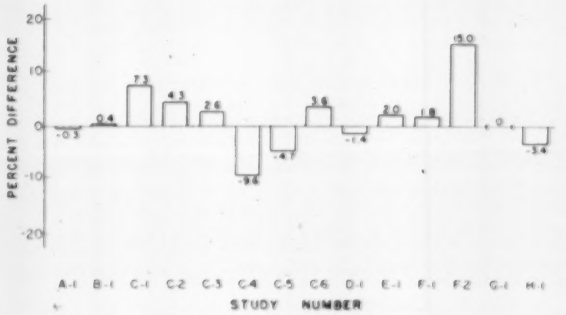



FIG. 4. Results of 25 Percent Sub-Samples

Percent difference between normal time—performance sampling and normal time—time study.

Figure 3 shows similar information for a sample size of 50% of that shown in Figure 2. In this case the average difference is 6.6% with a high of +14.6% and a low of −9.2%. Likewise, Figure 4 shows the results when the sample size equals to 25% of the original. In this case the average difference is 17.6% with a range of +15.0% and −9.6%.

We have observed in actual practice that some people appear to get satisfactory results by using a considerably smaller sample size than that recommended. Therefore, we have included a 50% and a 25% sample in order to compare results.

| Experimental Group | | | Operation Description | Total Actual Time | Ratio-Delay Analysis | | | | | | | | | | | | Time Study | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Full study | | | | 50% Sub-sampling | | | | 25% Sub-sampling | | | | | | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) | (19) | (20) |
| Company | Study Number | Number of operators simultaneously performing the operation | | Minutes | Total Number of observations ($n$) | Percent of total actual time spent on measured work ($p_m$) | Absolute sampling error in $p_m$ at 95% confidence level ($e$) | Percent of measured work time operator controlled ($P_c$) | Total number of observations ($n$) | Percent of total actual time spent on measured work ($p_m$) | Absolute sampling error in $p_m$ at 95% confidence level ($e$) | Percent of measured work time operator controlled ($P_c$) | Total number of observations ($n$) | Percent of total actual time spent on measured work ($p_m$) | Absolute Sampling error in $p_m$ at 95% confidence level ($e$) | Percent of measured work time operator controlled ($P_c$) | Total units produced | Normal time from time study in minutes per unit | Performance Index from time standard |
| | | | | | | % | % | % | | % | % | | | % | % | | | | |
| A | 1 | 10 | Mechanical Subassembly | 13,650 | 720 | 98.7 | ±0.8 | 100 | 360 | 98.3 | ±1.3 | 100 | 179 | 97.8 | ±2.2 | 100 | 16,314 | 1.00 | 121.9 |
| B | 1 | 3 | Electrical Subassembly | 1,380 | 596 | 89.9 | ±2.5 | 100 | 300 | 89.3 | ±3.5 | 100 | 150 | 90.7 | ±5.0 | 100 | 6,468 | 0.241 | 125.6 |
| C | 1 | 1 | Cutting | 460 | 766 | 74.5 | ±3.2 | 100 | 394 | 77.9 | ±4.1 | 100 | 197 | 79.2 | ±5.7 | 100 | 7,290 | 0.0421 | 90.2 |
| | 2 | 1 | Notching | 460 | 766 | 80.0 | ±2.9 | 100 | 383 | 79.4 | ±4.1 | 100 | 191 | 79.1 | ±5.8 | 100 | 6,800 | 0.0627 | 115.9 |
| | 3 | 1 | Cutting | 460 | 766 | 83.2 | ±2.7 | 100 | 382 | 84.3 | ±3.7 | 100 | 193 | 83.9 | ±5.2 | 100 | 8,061 | 0.0346 | 72.9 |
| | 4 | 1 | Cutting-Bandsaw | 460 | 766 | 75.6 | ±3.1 | 100 | 387 | 74.7 | ±4.3 | 100 | 193 | 72.5 | ±6.3 | 100 | 6,544 | 0.0488 | 93.7 |
| | 5 | 1 | Hand Nailing | 460 | 766 | 90.9 | ±1.6 | 100 | 384 | 90.6 | ±2.9 | 100 | 192 | 90.1 | ±4.2 | 100 | 345 | 0.741 | 61.1 |
| | 6 | 1 | Machine Nailing | 460 | 766 | 75.8 | ±3.1 | 100 | 383 | 76.8 | ±4.2 | 100 | 191 | 77.5 | ±5.9 | 100 | 1,068 | 0.277 | 84.8 |
| D | 1 | 4 | Typing Invoices | 5,580 | 458[2] | 73.6 | ±4.6 | 100 | 226 | 75.2 | ±5.6 | 100 | 114 | 74.6 | ±7.8 | 100 | 2,790 | 1.47 | 99.9 |
| E | 1 | 7 | Packaging | 9,660 | 598 | 80.7 | ±3.2 | 100 | 298 | 82.2 | ±4.3 | 100 | 147 | 83.7 | ±6.0 | 100 | 93,732 | 0.103 | 123.3 |
| F | 1 | 8 | Assembly | 15,372 | 649 | 83.7 | ±2.8 | 100 | 326 | 83.7 | ±4.0 | 100 | 162 | 86.4 | ±5.3 | 100 | 291 | 99.7 | 94.9 |
| | 2 | | Drill Sheet Metal | 2,646 | 540 | 93.0 | ±2.2 | 33.1 | 269 | 92.6 | ±3.1 | 34.5 | 134 | 93.3 | ±4.2 | 34.4 | 960 | 2.33 | 85.1 |
| G | 1 | 1 | Drill, Bore & Ream Casting on Turret Lathe | 4,600 | 300[2] | 95.0 | ±2.5 | 75.8 | 151 | 96.0 | ±3.1 | 73.1 | 75 | 96.0 | ±4.4 | 69.4 | 2,790 | 1.72 | 109.8 |
| H | 1 | 4 | Grinding | 1,840 | 396[2] | 68.9 | ±4.6 | 46.5 | 198 | 64.1 | ±6.6 | 48.0 | 99 | 67.7 | ±9.2 | 44.8 | 10,900 | 0.119 | 102.3 |

[1] This symbol denotes that the normal time was obtained from an established time standard rather than a concurrent time study.
[2] These companies were unable to obtain the desired 600 observations.

## *Explanatory Guide to Table 1*

*Column 1*—Company Code

Companies are identified by code letter to maintain their anonymity.

*Column 2*—Study Number

Studies are numbered beginning with No. 1 for each company.

*Column 3*—Number of Operators Simultaneously Performing the Operation

In certain instances more than one operator was engaged in performing the same operation. In such cases all operators were included in the experimental group. The production of each operator was individually tabulated. In each case the operation was a one-operator task—not group work.

*Example:* For Company A, there were 10 employees, individually measured, performing the operation selected for study.

*Column 4*—Operation Description

A brief indication as to the type of operation studied is presented.

*Example:* Mechanical Sub-assembly

*Column 5*—Total Actual Time

This is the total cumulative clock time spent on the selected operation by the experimental group during the period covered by the study.

*Example:* 13,650 minutes were spent on the operation by the 10 employees of Company A while the study was being made.

*Column 6*—Total Number of Observations

The total number of observations taken in the course of the study. This includes measured work (i.e., elements of the operation which are included in the normal time), unmeasured work (i.e., productive work which was not included in the normal time), unavoidable delays and avoidable delays.

*Example:* 720 observations were taken during the study.

*Column 7*—Percent of Total Actual Time Spent on Measured Work

This represents the ratio of the measured work time (i.e., time during which elements of the operation which are included in normal time are being performed) to the actual time. The quantity is determined in accordance with conventional ratio-delay practice. Thus, the percent of actual time spent on measured work is determined by dividing the number of measured work observations (Column 21) by the total number of observations (Column 6).

*Example:*

$$p_m = \frac{n_m}{n} = \frac{\text{Column 21}}{\text{Column 6}}$$

$$p_m = \frac{711}{720} = 0.987 = 98.7\%$$

*Where:*

$p_m$ = percent of actual time spent on measured work

$n_m$ = number of measured work observations

$n$ = total number of observations

LE 1

*ling—Results*[1]

Performance Sampling Study

| Full study | | | | | | 50% Sub-sampling | | | | | | 25% Sub-sampling | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (21) Number of measured work observations ($p_m$) | (22) Performance index from performance sampling | (23) Absolute sampling error in performance index from performance sampling at 95% confidence level | (24) Normal time from performance sampling in minutes per unit | (25) Absolute difference between normal time—performance sampling and normal time—time study Col (24)—Col (19) | (26) Percent difference between normal time—performance sampling and normal time—time study Col (25) / Col (19) | (27) Number of measured work observations ($p_m$) | (28) Performance index from performance sampling | (29) Absolute sampling error in performance index from performance sampling at 95% confidence level | (30) Normal time from performance sampling in minutes per unit | (31) Absolute difference between normal time—performance sampling and normal time—time study Col (30)—Col (19) | (32) Percent difference between normal time—performance sampling and normal time—time study Col (31) / Col (19) | (33) Number of measured work observations ($p_m$) | (34) Performance index from performance sampling | (35) Absolute sampling error in performance index from performance sampling at 95% confidence level | (36) Normal time from performance sampling in minutes per unit | (37) Absolute difference between normal time—performance sampling and normal time—time study Col (36)—Col (19) | (38) Percent difference between normal time—performance sampling and normal time—time study Col (37) / Col (19) |
| | | | | | % | | | | | | % | | | | | | % |
| 711 | 123.6 | ±2.1 | 1.02 | 0.02 | 2.0 | 354 | 122.0 | ±2.2 | 1.00 | 0 | 0 | 175 | 121.8 | ±3.0 | 0.997 | −0.003 | −0.3 |
| 536 | 124.7 | ±2.1 | 0.239 | −0.002 | −0.8 | 268 | 124.6 | ±3.1 | 0.237 | −0.004 | −1.7 | 136 | 125.1 | ±4.2 | 0.242 | 0.001 | 0.4 |
| 571 | 91.2 | ±2.1 | 0.0429 | 0.0005 | 1.2 | 307 | 91.2 | ±2.7 | 0.0448 | 0.0024 | 5.7 | 156 | 91.3 | ±3.7 | 0.0455 | 0.0031 | 7.3 |
| 613 | 122.4 | ±1.2 | 0.0662 | 0.0035 | 5.6 | 304 | 122.4 | ±1.5 | 0.0657 | 0.0030 | 4.8 | 151 | 122.3 | ±2.1 | 0.0654 | 0.0027 | 4.3 |
| 637 | 74.2 | ±1.6 | 0.0352 | 0.0006 | 1.7 | 322 | 74.3 | ±2.3 | 0.0357 | 0.0011 | 3.2 | 162 | 74.2 | ±3.3 | 0.0355 | 0.0009 | 2.6 |
| 579 | 87.9 | ±2.3 | 0.0467 | −0.0031 | −6.2 | 289 | 88.2 | ±3.2 | 0.0464 | −0.0034 | −6.8 | 140 | 88.3 | ±4.8 | 0.0450 | −0.0048 | −9.6 |
| 696 | 58.7 | ±1.4 | 0.711 | −0.030 | −4.1 | 348 | 58.9 | ±2.11 | 0.712 | −0.029 | −3.9 | 173 | 58.8 | ±3.4 | 0.706 | −0.035 | −4.7 |
| 581 | 83.3 | ±2.8 | 0.272 | −0.005 | −1.8 | 294 | 85.8 | ±4.1 | 0.284 | 0.007 | 2.5 | 148 | 86.1 | ±5.7 | 0.287 | 0.010 | 3.6 |
| 337 | 96.4 | ±2.1 | 1.42 | −0.05 | −3.4 | 170 | 96.2 | ±2.8 | 1.45 | −0.02 | −1.4 | 85 | 96.9 | ±4.1 | 1.45 | −0.02 | −1.4 |
| 483 | 121.9 | ±3.2 | 0.101 | −0.002 | −2.0 | 245 | 121.1 | ±4.5 | 0.103 | 0 | 0 | 123 | 122.0 | ±6.1 | 0.105 | 0.002 | 2.0 |
| 543 | 92.8 | ±1.0 | 59.4 | −1.3 | −2.1 | 273 | 93.1 | ±1.4 | 59.6 | −1.1 | −1.8 | 140 | 93.5 | ±2.1 | 61.8 | 1.1 | 1.8 |
| 502 | 98.2 | ±0.9 | 2.69 | 0.36 | 15.5 | 249 | 98.1 | ±1.2 | 2.67 | 0.34 | 14.6 | 125 | 97.9 | ±1.8 | 2.68 | 0.35 | 15.0 |
| 285 | 109.2 | ±3.8 | 1.71 | −0.01 | −0.6 | 145 | 109.0 | ±4.2 | 1.73 | 0.01 | 0.6 | 72 | 108.9 | ±6.0 | 1.72 | 0 | 0 |
| 273 | 100.1 | ±1.3 | 0.116 | −0.003 | −2.5 | 127 | 99.4 | ±2.0 | 0.108 | −0.011 | −9.2 | 67 | 100.2 | ±1.8 | 0.115 | −0.004 | −3.4 |

*Column 8*—Absolute sampling error in $p_m$ at 95% confidence level.

The absolute sampling error is ±1.96 times the standard deviation of the sample percentage. This represents the range about the observed percentage within which the population percentage can be expected to lie 95 out of 100 times. 1.96 and −1.96 are the 0.975 and 0.025 fractile values of the cumulative frequency distribution of the standardized normal variable.

*Example:*

$$\epsilon = \pm 1.96\, s_{p_m}$$

$$s_{p_m} = \sqrt{\frac{p_m(1 - p_m)}{n}}$$

$$\epsilon = \pm 1.96 \sqrt{\frac{p_m(1 - p_m)}{n}}$$

$$\epsilon = \pm 1.96 \sqrt{\frac{0.987(1-0.987)}{720}} = \pm 0.008 = \pm 0.8\%$$

*Where:*

$s_{p_m}$ = standard deviation of the sample percentage

$p_m$ = percent of actual time spent on measured work

$\epsilon$ = absolute sampling error in $p_m$

$n$ = total number of observations

*Column 9*—Percent of Measured Work Time Which is Operator Controlled

This is the ratio of "measured work time—operator controlled" to the measured work time. This quantity is similarly determined by ratio-delay analysis. Accordingly, the percent of measured work time which is operator controlled is estimated by dividing the number of measured work operator controlled observations by the number of measured work observations (Column 21). "Measured work time-operator controlled" is that time during which those elements which are included in the normal time, and operator controlled, are being performed. Operator controlled elements are considered to be that portion of the total operation which can be influenced by the employee's skill and effort.

*Example:*

$$p_o = \frac{n_o}{n_m}$$

$$p_o = \frac{711}{711} = 1.00 = 100\%$$

*Where:*

$p_o$ = percent of measured work time which is operator controlled

$n_o$ = number of measured work—operator controlled observations

$n_m$ = number of measured work observations

*Columns 10 through 13*

These columns are computed in the same manner as Columns 6 through 9. The only difference is that the data used are based upon a 50% systematic sub-sampling of the original complete study.

*Columns 14 through 17*

These columns are computed in the same manner as Columns 6 through 9. The only difference is that the figures used are based upon a 25% systematic sub-sampling of the original complete study.

*Column 18*—Total Units Produced

The actual total number of units produced by the participating operator or group of operators during the period covered by the study.

*Example:* The 10 operators of Company A produced 16,314 units (sub-assemblies) during the test period.

*Column 19*—Normal Time—Time Study

The time required under standard conditions to perform the measured work at a normal pace but excluding any allowances. This normal time in minutes per unit was established by time study. In some instances the normal time was determined by time studies made by the same engineer who made the performance sampling studies and in other cases the normal time was obtained from data already available.

*Example:* 1.00 minutes per unit is the normal time for the operation studied at Company A.

*Column 20*—Performance Index—Time Study

The performance index from time study is determined by dividing the earned normal minutes by the measured work time in minutes and expressing the result as a percentage. The earned normal minutes are the product of the total units produced (Column 18) and the normal time from time study (Column 19). Measured work time is the percent of actual time spent on measured work (Column 7) multiplied by the total actual time (Column 5).

*Example:*

$$\text{Performance Index} = \frac{(\text{Column 18})(\text{Column 19})}{(\text{Column 7})(\text{Column 5})} \times 100$$

$$\text{Performance Index} = \frac{(16314)(1.00)}{(0.987)(13650)} \times 100 = 121.6$$

*Column 21*—Number of Measured Work Observations

This represents the total number of observations in which the observed state of the operation was an element included in the normal time.

*Example:* 711 of the 720 observations made during the Company A study were of measured work.

*Column 22*—Performance Index—Performance Sampling

This quantity is the arithmetic mean of the performance ratings made whenever the observed state of the operation was measured work. Although separately recorded on the data sheet, "measured work machine controlled" observations were added to the operator performance ratings as 100% performance observations. Measured work machine controlled is the portion of the operation, included in the normal time, which is mechanically paced so that it cannot be affected by the operator's skill and effort.

*Example:*

$$\text{Performance Index} = \frac{\text{sum of the individual performance ratings}^2}{\text{Column 21}}$$

$$\text{Performance Index} = \frac{87901}{711} = 123.6$$

*Column 23*—Absolute Sampling Error in Performance Index from Performance Sampling at 95% Confidence Level

This quantity represents the range about the sample mean performance index which will include the population mean performance index 95 out of 100 times in the long run. The equation for computing this quantity is given by:

*Example:*

$$d = \pm \frac{s}{\sqrt{n_m \alpha}}$$

$$d = \pm \frac{12.3}{\sqrt{(711)(0.05)}} = \pm 2.1$$

*Where:*

- $d$ = absolute sampling error in performance index
- $s$ = sample standard deviation of performance ratings
- $n_m$ = number of measured work observations
- $\alpha$ = level of statistical significance ($1 - \alpha$ is the confidence level)

*Column 24*—Normal Time—Performance Sampling

This normal time is the product of the average performance index (performance index, Column 22) multiplied by the selected time. The selected time is determined by dividing the measured work time (i.e., percent of actual time spent on measured work, Column 7, multiplied by the total actual time, Column 5) by the total units produced (Column 18).

*Example:*

$$\text{normal time} = \frac{(\text{Column 7})(\text{Column 5})}{(\text{Column 18})} \times \frac{\text{Column 22}}{100}$$

$$\text{normal time} = \frac{(0.987)(13650)}{16314} \times \frac{123.6}{100}$$

$$\text{normal time} = 1.02 \text{ minutes per unit}$$

*Column 25*—Absolute Difference Between Normal Time—Performance Sampling and Normal Time—Time Study.

As the name implies this quantity is the algebraic difference between Columns 24 and 19.

*Example:* Column 24 − Column 19 = 1.02 − 1.00 = 0.02 minutes per unit

*Column 26*—Percent Difference Between Normal Time—Performance Sampling and Normal Time—Time Study

This quantity is the algebraic difference between Columns 24 and 19, as given by Column 25, divided by Column 19 and expressed as a percentage.

*Example:* $\dfrac{\text{Column 25}}{\text{Column 19}} = \dfrac{0.02}{1.00} \times 100 = 2.0\%$

*Columns 27 through 32*

These columns are computed in the same manner as Columns 21 through 26. The only difference is that the data used are based upon a 50% systematic sub-sampling of the original complete study.

*Columns 33 through 38*

These columns are computed in the same manner as Columns 21 through 26. The only difference is that the data used are based upon a 25% systematic sub-sampling of the original complete study.

[2] Sum of individual performance ratings are obtained from the original data sheets.

### Conclusions

1. Work sampling will give time standards for repetitive standardized manual tasks which are substantially the same as standards obtained by time study.

2. For an activity where a production count is not easy to obtain, such as indirect labor operations, it is possible to obtain an average performance index of the operator studied during the period studied using performance sampling.

3. The measurements mentioned above can be made with a pre-assigned degree of reliability.

4. In many instances work can be measured by sampling in less time and at less cost than is required by time study.

5. In work sampling the observer makes an instantaneous check of the operator's performance at random intervals during the working day, thus making prolonged time studies unnecessary.

6. No stop watch or other timing device is needed for work sampling studies.

7. Work sampling studies may be taken over a period of days or weeks, thus decreasing the chance of day-to-day or week-to-week variation affecting the results.

8. This type of study may be interrupted at any time without affecting the results.

9. Even in a plant where methods are not standardized and job descriptions are nonexistent, an average performance index by operator or by department can be obtained. Such data could show standard hours of productive work, average performance index, idle time and delays, and a breakdown of the various reasons for the nonproductive time.

## Appendix

### *Development of Statistical Relationships Directly Applicable to Performance Sampling*

The definition of symbols used in the subsequent discussion are given below:

$\alpha$ = level of significance
$1 - \alpha$ = confidence level
$\beta$ = relative kurtosis of the distribution
$d$ = variation between the population mean and the sample mean
$e$ = absolute sampling error in $p_m$, the percent of actual time spent on measured work
$i$ = length of the class intervals of the grouped frequency distribution
$n$ = total number of observations
$n_m$ = number of measured work observations
$n_c$ = number of measured work observations which are operator controlled
$p_m$ = percent of actual time spent on measured work
$p_c$ = percent of measured work time which is operator controlled
$s$ = sample standard deviation of performance indices
$\sigma$ = population standard deviation of performance indices
$\sigma_x$ = standard deviation of the distribution of sample standard deviations
$\sigma_{\bar{x}}$ = standard deviation of the distribution of sample means
$v_j$ = $j^{th}$ moment about the assumed calculation mean, $j = 1, 2, 3$ and 4
$\pi_2$ = second moment about the actual sample mean
$\pi_4$ = fourth moment about the actual sample mean
$\bar{x}$ = sample mean of performance indices
$\eta$ = population mean of performance indices

*Total Actual Time:* Total work period in minutes covered by the study minus scheduled rest periods and lunch periods.

*Measured Work:* Elements of the Operation which are included in the normal time.

*Measured Work—Operator Controlled:* That portion of the total measured work which can be affected by the employee's skill and effort.

*Measured Work—Machine Controlled:* That portion of the measured work which is mechanically paced (such as power feed and speed) so that it cannot be influenced by the operator's skill and effort.

*Normal Time:* The time required under standard conditions to perform the measured work at a normal pace excluding any allowances.

*Performance Index:* For the purposes of this study, the quotient found by dividing the earned normal minutes (normal time per piece multiplied by the total number of pieces produced) by the measured work time in minutes. The measured work time is determined by multiplying the total actual clock time by the percent of the total actual time spent on measured work.

*Unmeasured Work:* Productive work which is not included in the normal time. In most studies only the repetitive elements occurring at least once a cycle were included in the normal time. For example, such elements as inspect work, line trays, record production, which occur only infrequently were omitted from the normal time. These exclusions were made to simplify the study and to increase the probable accuracy.

The development of relationships applicable to performance sampling was based upon Tchebycheff's Inequality and the Central Limit Theorem. Tchebycheff's theorem states that, regardless of the mathematical form of the distribution function, the area under the distribution curve lying farther from the mean than $k$ standard deviations is always less than $1/k^2$. Thus less than $1/k^2$ of the sample mean distribution is farther from the population mean than $k\ \sigma_{\bar{x}}$. Letting $d$, the difference between the population mean and the sample mean equal the $k$ standard deviations, $d = \sigma_{\bar{x}} k$. Solving for $1/k$:

$$\frac{1}{k} = \frac{\sigma_{\bar{x}}}{d}$$

Squaring both sides:

$$\frac{1}{k^2} = \frac{\sigma_{\bar{x}}^2}{d^2}$$

The Central Limit Theorem shows that when the population mean and variance are finite, the sample distribution of means approaches normaley as the sample size increases. Unless the population is extremely skewed, or otherwise peculiar, sample means are fairly normally distributed for relatively small sample sizes. Thus the use of a minimum sample size of 100 would seem to justify the applying of the normal distribution relationships to the distribution of sample means. Normally distributed means vary about the population mean with a standard deviation equal to the

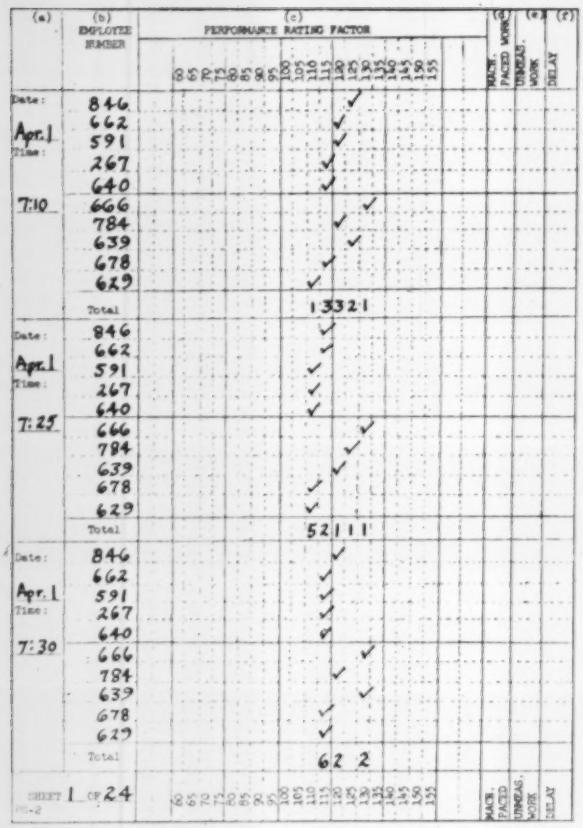



Fig. 5. Sample Data Sheet From Company A Study

population standard deviation divided by the square root of the sample size or $\sigma_{\bar{x}} = \dfrac{\sigma}{\sqrt{n_m}}$. Substituting:

$$\frac{1}{k^2} = \frac{\sigma^2}{d^2 n_m}$$

If the confidence level $1 - \alpha$ is to equal the total area included in the interval between the population mean plus and minus $d$, the level of significance $\alpha$, must equal $1/k^2$. Substituting:

$$\alpha = \frac{\sigma^2}{d^2 n_m}$$

Solving for $n_m$:

$$n_m = \frac{\sigma^2}{d^2 \alpha}$$

An approximate sample size can be obtained by making an estimate of $\sigma$. The sufficiency of a particular sample, based upon an estimated $\sigma$ may be tested by computing the upper confidence limit of $\sigma$. If the computed upper confidence limit is less than the assumed $\sigma$, the sample size was sufficient for the desired accuracy and statistical confidence. From Tchebycheff's Inequality, the upper confidence limit is given by the expression $s + k\sigma_s$, where the desired significance level $\alpha = 1/k^2$. The standard deviation of the distribution of sample standard deviations is approximated by $\sigma_s = \dfrac{cs}{\sqrt{2n_m}}$, where $c = \left[1 + \dfrac{\beta - 3}{2}\right]^{\frac{1}{2}}$. Substituting:

$$\text{upper confidence limit for } \sigma = s + \frac{kcs}{\sqrt{2n_m}}$$

but $k = \dfrac{1}{\sqrt{\alpha}}$:

$$\text{upper confidence limit for } \sigma = s + \frac{cs}{\sqrt{2n_m\,\alpha}}$$

*Sample Calculations for Company "A" Full Study*

The Daily Summary Table, given below, shows the daily and total frequency distributions of performance indices taken during the Company A Study. Figure 5 is a sample data sheet from Company A.

Daily Summary

| Performance Index | April 1 | April 2 | April 3 | Total |
|---|---|---|---|---|
| 100 | 3 | 6 | 1 | 10 |
| 105 | 13 | 22 | 9 | 44 |
| 110 | 32 | 21 | 24 | 77 |
| 115 | 48 | 45 | 17 | 110 |
| 120 | 47 | 49 | 39 | 135 |
| 125 | 27 | 28 | 56 | 111 |
| 130 | 26 | 13 | 22 | 61 |
| 135 | 15 | 8 | 11 | 34 |
| 140 | 14 | 15 | 22 | 51 |
| 145 | 8 | 20 | 27 | 55 |
| 150 | 2 | 10 | 11 | 23 |
| Measured work observations | 235 | 237 | 239 | 711 |
| Delay and unmeasured work observations | 5 | 3 | 1 | 9 |
| Total observations | 240 | 240 | 240 | 720 |

Computations are greatly facilitated by the use of a frequency distribution and expressing deviations from an arbitrary origin in terms of the class interval. The following table shows such calculations made for the Company A Study.

| Performance Index $x$ = Class Midpoint | Number of Indices $a$ | $x = x_0 + iu = 120 + 5u$ | | | | |
|---|---|---|---|---|---|---|
| | | $u$ | $au$ | $au^2$ | $au^3$ | $au^4$ |
| 100 | 10 | −4 | −40 | 160 | −640 | 2560 |
| 105 | 44 | −3 | −132 | 396 | −1188 | 3564 |
| 110 | 77 | −2 | −154 | 308 | −616 | 704 |
| 115 | 110 | −1 | −110 | 110 | −110 | 110 |
| 120 | 135 | 0 | 0 | 0 | 0 | 0 |
| 125 | 111 | 1 | 111 | 111 | 111 | 111 |
| 130 | 61 | 2 | 122 | 244 | 488 | 976 |
| 135 | 34 | 3 | 102 | 306 | 918 | 2754 |
| 140 | 51 | 4 | 204 | 816 | 3264 | 13056 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 145<br>150 | 55<br>23 | 5<br>6 | 275<br>138 | 1375<br>828 | 6875<br>4968 | 34375<br>29808 |
| Measured work observations | 711 | | 516 | 4654 | 14070 | 88018 |
| Delay and unmeasured work observations | 9 | | | | | |
| Total observations | 720 | | | | | |

1. Moments about computation mean, $x_0 = 120$

$$v_1 = \frac{\sum au}{n_m} = \frac{516}{711} = 0.726$$

$$v_2 = \frac{\sum au^2}{n_m} = \frac{4654}{711} = 6.546$$

$$v_3 = \frac{\sum au^3}{n_m} = \frac{14070}{711} = 19.789$$

$$v_4 = \frac{\sum au^4}{n_m} = \frac{88018}{711} = 123.80$$

2. Moments about actual sample mean

Second moment, $\pi_2 = i^2(v_2 - v_1^2) = (5)^2(6.546 - (0.726)^2) = 150.5$

Fourth moment, $\pi_4 = i^4(v_4 - 4v_1v_3 + 6v_1^2v_2 - 3v_1^4)$

$\pi_4 = (5)^4(123.80 - 4(0.726)(19.789) + 6(0.726)^2(6.546) - 3(0.726)^4)$

$\pi_4 = 53500$

3. Check of the adequacy of the sample size

a. Upper confidence limit for $\sigma$.

$$\beta = \frac{\pi_4}{\pi_2^2} = \frac{53500}{(150.5)^2} = 2.36$$

$$c = \left[1 + \frac{\beta - 3}{2}\right] = \left[1 + \frac{2.36 - 3}{2}\right] = 0.835$$

$$s = \sqrt{\pi_2} = \sqrt{150.5} = 12.27$$

for level of significance, $\alpha = 0.05$

upper confidence limit for $\sigma = s + \frac{cs}{\sqrt{2n_m\alpha}}$

upper confidence limit for $\sigma = 12.27 + \frac{(0.835)(12.27)}{\sqrt{2(711)(0.05)}} = 16.1$

b. The sample size was based upon ratio-delay requirements. In order to check the adequacy of sample size in terms of performance sampling, the population standard deviation corresponding to the desired accuracy and statistical confidence is taken as the "assumed" $\sigma$. Assumed value of $\sigma$ for level of significance $\alpha = 0.05$, and maximum desired variation between sample and population means, $d = 5$: $\sigma = d\sqrt{n_m\alpha} = 5\sqrt{711(0.05)} = 29.8$

c. Since assumed $\sigma$ of 29.8 is greater than upper confidence limit of 16.1, the sample size was sufficient for the desired accuracy and statistical confidence.

4. Percent of total actual time spent on measured work

$$p_m = \frac{n_m}{n} = \frac{711}{720} = 0.987 = 98.7\%$$

5. Absolute sampling error in $p_m$ at 95% confidence level

$$e = \pm 1.96\sqrt{\frac{p_m(1 - p_m)}{n}}$$

$$= \pm 1.96\sqrt{\frac{0.987(1 - 0.987)}{720}} = \pm 0.008 = \pm 0.8\%$$

6. Measured work time

Measured work time = $p_m$ (Total Actual Time)

Measured work time = 0.987(13650) = 13473 minutes

7. Performance index—time study

Performance Index

$$= \frac{\text{(normal time)(production)}}{\text{(measured work time)}} \times 100$$

Performance Index

$$= \frac{1.00\text{(minutes/unit)}\ 16314\text{(units)}}{13473\text{(minutes)}} \times 100 = 121.6$$

8. Performance index—performance sampling

Performance index = $x_0 + iv_1 = 120 + 5(0.726) = 123.6$

9. Absolute sampling error in performance index—performance sampling at 95% confidence level.

$$d = \pm \frac{s}{\sqrt{n_m\alpha}} = \frac{12.3\text{(See 3 above)}}{\sqrt{(711)(0.05)}} = \pm 2.1$$

10. Normal time—performance sampling

$$\text{Normal time} = \frac{\text{(measured work time)}}{\text{(production)}} \times \frac{\text{performance index-performance sampling}}{100}$$

$$\text{Normal time} = \frac{13473\text{(minutes)}}{16314\text{(units)}} \times \frac{123.6}{100}$$

$$= 1.02 \text{ minutes/unit}$$

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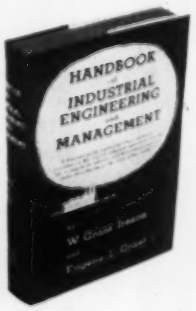


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# Queueing Theory in Organization Design[1]

By D. G. Malcolm

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Problems of "interference," or "queueing" as the subject is becoming more popularly known, have been recognized by industrial engineers [1, 2] in determining the optimum number of machines etc. to be tended or repaired by an individual operator. However, in the references cited, development has been made for a *single* operator, or workman, tending a variable number of machines and, therefore, lacks the generality required for investigation of more optimal work assignment procedures which involve the possibility of a *group* of workers being assigned to a *group* of machines, or work stations.

To provide the theoretical background for this general type of problem which has many implications in organizational design, a portion of mathematical probability theory known as stochastic processes must be employed. The purpose of this paper may therefore be stated as being threefold:

(1) *A Queueing Model:* to present the more general mathematical model, or equations, required in such analyses. This will be referred to as a "stochastic process" or queueing model. The term "waiting line" analysis is also descriptive of the same problem. Monte Carlo methods are also useful in this type of problem and should be seriously considered as an alternate, often more economical, method.

(2) *Economic Decision Criteria:* to demonstrate a way in which results derived from the queueing model may be employed in determining the most economic work assignments.

(3) *Application to Organization Design:* to present and discuss an application of these methods to a problem in designing the organization for a production department engaged in engine testing.

## Problem

To fulfill objectives (1) and (2) listed above let us state a problem which we may explore:

There exists a number of machines which require random emergency service or maintenance, known to occur at some average rate, i.e. with a Servicing Factor $\lambda/\mu$ of known value. It is our problem to determine the optimum number of repairmen which should be assigned to this job and specify the most economical size of group ($s$) in which they should work. The queueing theory approach will be used.

[1] Adapted from a paper delivered at the Informal Seminar in Operations Research, The Johns Hopkins University, Baltimore, Maryland, February 23, 1955.

## Symbols

Before proceeding into the method, a few words concerning queueing problems and the terms or symbols used are in order. For our purposes, queueing problems may be characterized by the following factors: (A) *Something to be Serviced:* this may be customers in a restaurant, airplanes waiting to land, or, as in our problem a number of machines requiring maintenance. (B) *An Arrival Rate:* how often do customers arrive? how often does a machine "arrive" for repair? or how long does the machine run between breakdowns? what are the frequency distributions of the above? (C) *A Servicing Rate:* what time is required to perform the requested service? what is the frequency distribution of these times? (D) *A Number of Servicing Units:* how many waitresses are employed? how many runways at the airport? how many repairmen?

The symbols which will be used are listed here for reference:

$m$ = total number of machines which are involved

$r$ = number of repairmen

$P_n$ = Probability that $n$ of the $m$ machines require service at a given time

$P_0$ = Probability that none (0) of the $m$ machines require service at a given time

$1/\mu$ = Expected Service Time: i.e., the mean of the distribution of actual service times (or the reciprocal of the servicing rate $\mu$)

$1/\lambda$ = Expected Running Time: i.e., the mean of the distribution of actual running times (or the reciprocal of the arrival rate $\lambda$)

$\lambda/\mu$ = Servicing Factor: the ratio of the Expected Service Time to the Expected Running Time

$R$ = Expected number of $m$ machines running at any given time as determined from the Queueing model

$S$ = Expected number of the $m$ machines being serviced at any given time (from Queueing model)

$W$ = Expected number of the $m$ machines waiting for service at any given time (from Queueing model)

At any given time $R + S + W = m$

## Queueing Model

The objective of this analysis is to calculate the probability of occurrence for each possible combination of machines that might require service at a given time. These combinations of 0, 1 . . . $m$ machines requiring service simultaneously are referred to as the "states" of the system. Then, by weighted addition of the probabilities

of those "states" in which waiting or interference can occur (those states where all the repairmen are already working), the total expected number of machines waiting $W$ can be computed. From this, as will be demonstrated, may be computed the expected (Average) percent Running Time that the given system of machines and repairmen should achieve. This is our first objective.

The following equations have been developed as an extension of the work of C. Palm [4] as reported by Feller [3]. They result from the solution of steady-state difference equations which describe the sum of probabilities of the various possible ways a given number of machines may require service at a given time.[2]

$$\frac{P_n}{P_0} = \frac{m!}{n!(m-n)!}\left(\frac{\lambda}{\mu}\right)^n \text{ where } 0 < n < r \quad \text{Eq. (1)}$$

$$\frac{P_n}{P_0} = \frac{m!}{r!r^{n-r}(m-n)!}\left(\frac{\lambda}{\mu}\right)^n \text{ where } n \geq r \quad \text{Eq. (2)}$$

Use of these equations (1, 2) will be made by reference to Table 1 which gives us estimates of the Expected number of machines that might be observed Running, being Serviced or Waiting Service at a given time. It should be pointed out that variations from these values are to be expected; these values, in one sense, represent the average of many observations. Equation (3) indicates the relationship of these expected values and how they may be computed.

Machines Running + Machines being Serviced + Machines Waiting = $m$

$$R + S + W = m$$

$$\sum_{n=0}^{m}(m-n)P_n + \left(\frac{\lambda}{\mu}\right)\sum_{n=0}^{m}(m-n)P_n + \sum_{n=r+1}^{m}(n-r)P_n = m \quad \text{Eq. (3)}$$

It will be noted that the summation for $S$ is equal to $(\lambda/\mu)$ times the summation for $R$. Therefore,

$$R + (\lambda/\mu)R + W = m$$

The expected number of machines Running is

$$R = \frac{m - W}{1 + (\lambda/\mu)}$$

and expressed as a percent of $m$, the total number of machines

$$\%\text{ Machine Running Time} = \frac{1 - (W/m)}{1 + (\lambda/\mu)} \quad \text{Eq. (4)}$$

[2] The reader is encouraged to read the development by Feller and Palm for the basic assumptions made in setting up and solving the difference equations. The assumptions made in the derivations put certain requirements upon the distributions of the running and service times in order that the equations are applicable. These assumptions are important and will be discussed later in the article.

TABLE 1

*Sum of Probabilities*

(Various Combinations of Machines Requiring Service At a Given Time)

| (1) Machines Requiring Service[a] ($n$) | (2) Machines Being Serviced[b] | (3) Machines Waiting Service[c] | (4) $P_n$[d] / $P_0$ | (5) $P_n$[f] |
|---|---|---|---|---|
| 0 | 0 | 0 | 1.000 | XXX |
| 1 | 1 | 0 | XXXX | XXX |
| 2 | 2 | 0 | XXXX | XXX |
| 3 | . | | XXXX | . |
| . | . | | . | . |
| . | . | | . | . |
| $r+1$ | $r$ | 0 | . | . |
| . | $r$ | 1 | . | . |
| . | $r$ | 2 | . | . |
| . | . | . | . | . |
| $m$ | $r$ | $m-r$ | XXXX | XXX |
| | | | $\sum \frac{P_n}{P_0} = \frac{1}{P_0}$[e] | 1.000 |

[a] Note there are $m + 1$ possible "states" (combinations of machines running or being down for service).

[b] Repairmen are assigned to machines requiring service until all repairmen are used.

[c] When $n = r + 1$ a "state" occurs wherein one machine will not be readily serviced: it must "wait." In this paper the probabilities of $r + 1$ and greater numbers of machines requiring service are of most interest.

[d] To arrive at the immediate objective (the values of $P_n$) it is necessary to solve first for the ratio $P_n/P_0$ since $P_0$ is unknown. Consequently, the appropriate Equation (1 or 2) is solved for all values of $n$; the values are entered in the column (4) and the sum of this column is taken.

[e] The sum of all probabilities for all the possible states is by definition equal to 1 ($\sum P_n = 1$) consequently $\sum \frac{P_n}{P_0} = \frac{1}{P_0}$ and $P_0$ is determined.

[f] From this, individual $P_n$ are computed by multiplying the value in the column (4) by $P_0$, giving the probability for any given number of machines requiring service at a given time.

For those not familiar with the notation in Equation (3) it should be pointed out that the notation indicates that $W$ is obtained by multiplying the value in column (3) of Table 1 by the corresponding value in column (5) and summing these products.

## Assumptions Involved in Basic Equations

It seems appropriate to include a short discussion of the basic assumptions involved in developing Equations (1, 2).

The probability that a machine (which is running) breaks down in a small interval of time, $h$, is $\lambda h$; when being serviced, the probability that it will return to the running state in an interval $h$ is $\mu h$. Another statement in the development is that $\lambda_n = (m - n)\lambda$ i.e., the probability of a breakdown from a number of machines is proportional to the number of machines running.

When dealing with any given system it is important that the assumptions are warranted. Tests of data col-

lected will show the distribution of individual service times and running times. If these are found to be of the Poisson-type distribution, use of the equations is warranted.

Even if the above is not shown, the equations will give satisfactory results when it is demonstrated that the number of machines requiring service at a given time is distributed similar to the distribution theoretically obtained (such as values in Table 1). Simple work-sampling studies may be used to demonstrate these attributes of the machines involved.

One can conceive of situations in which these assumptions would not hold, e.g. suppose we have 10 machines, each one of which runs *exactly* 9 hours before breaking down and then requires *exactly* 1 hour of service time. In this situation, after a short time, we would have one machine breaking down every hour. However, if in this situation the Running Time were not constant but varied with a standard deviation, $\sigma_E$, as great as one hour, then the assumptions above would hold. This follows from the unpublished work of C. E. Clark of the Operations Research Office. More generally he has shown that if breakdowns are periodic, but the Running Times vary with a standard deviation, $\sigma_E > 1/\mu$ (the Expected Service Time) that the Poisson process adequately approximates the situation. When such is the case the equations are applicable.

Jones indicates that a mix of machines with slightly different $(\lambda/\mu)$ introduces an insignificant error [1]. However, the effect of this has not been determined analytically.

At this point, we shall introduce the results of a series of calculations for Percent Machine Running Time for different values of $m$, $(\lambda/\mu)$ and $r$.[3] Tables 2 and 3 show the results of these calculations, each point in these tables involving setting up a table equivalent to Table 1 and by using the same procedure for calculation.

These data have been plotted in Figures 1 and 2, respectively, and permit a much better insight to the nature of the problem facing us. It is noted that the curves fall off quite rapidly when $r$ becomes less than $(\lambda/\mu)\cdot m$ and that each repairman added produces a smaller increase in

TABLE 2

*Expected Percent Machine Running Time*

($m = 20$)

| Number Repairmen $r$ | $\lambda/\mu$ = Servicing Factor | | | |
|---|---|---|---|---|
| | .01 | .05 | .1 | .15 |
| 1 | 98.81 | 85.77 | | |
| 2 | 99.01 | 94.38 | 84.18 | |
| 3 | 99.01 | 95.18 | 89.90 | 82.64 |
| 4 | 99.01 | 95.24 | 90.80 | 86.08 |
| 5 | 99.01 | 95.24 | 90.89 | 86.78 |
| 6 | 99.01 | 95.24 | 90.91 | 86.93 |

[3] More inclusive Tables of Expected Percent Machine Running Time have been calculated and are included at the end of the article. The author is indebted to J. C. Fernandez for his assistance in compiling these tables.

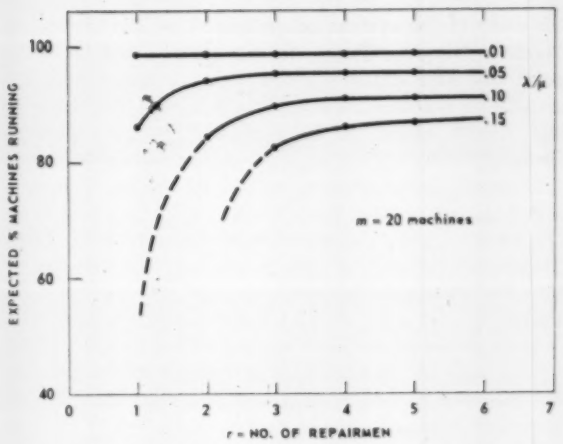


FIG. 1. Expected % of Machines Running vs No. Repairmen $m = 20$; various values of $\lambda/\mu$

TABLE 3

*Expected Percent Machine Running Time*

($m = 30$)

| Number of Repairmen $r$ | $\lambda/\mu$ = Servicing Factor | | |
|---|---|---|---|
| | .01 | .05 | .1 |
| 1 | 98.64 | | |
| 2 | 98.99 | 92.62 | |
| 3 | 99.01 | 94.92 | 85.94 |
| 4 | 99.01 | 95.24 | 89.25 |
| 5 | | 95.24 | 90.69 |
| 6 | | | 90.87 |
| 7 | | | 90.91 |

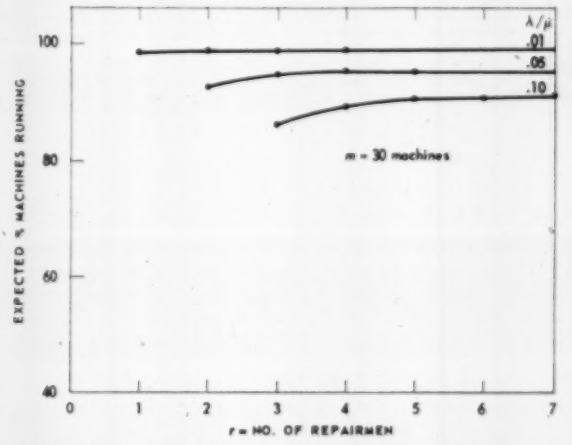


FIG. 2. Expected % Machines Running vs No. Repairmen $m = 30$; various values of $\lambda/\mu$

efficiency of the system (as measured by the percent of Machine Running Time). It is suggested that at some point the man added will cost more in wages than the increase in machine running time is worth. This leads to our second objective: to present Economic Decision Criteria.

However, before turning to this discussion, Figures 1 and 2 contain another item of interest, namely that there are two ways to increase the percent Running Time. These are, of course, by adding more men for servicing, or by some redesign of the machine to give it a lower Servicing Factor.

It should be pointed out that this servicing might indeed be the case of machine-loading instead of maintenance (as the term is herein discussed). In this situation the curves provide a dramatic picture of the effect of more automatic design. When viewed in this manner more complete data are provided in evaluating the economics of a technological advance versus manpower efficiently used.

## Economic Decision Criteria

Many cost equations could be proposed to evaluate the effect of added system efficiency versus manpower costs. The following is offered only for the purposes of showing the basis for a method for arriving at a decision concerning the least cost crew size.

If it is assumed that we are willing to make a decision on the basis of the number of men which will be needed for the least cost machine-hour, and that machines not running represent a loss, we can develop a Decision Equation:

Cost/machine-hr.

$$= \frac{R_H \cdot r}{m} + R_M(1 - \%\text{ Machine Running Time}) \quad \text{Eq. (5)}$$

where $R_H$ = *Rate/Hour* for the repairmen. It is assumed that no other work is assigned during idle time; $2.00/hour will be used throughout.

$R_M$ = *Rate/Hour* for machine time; An accounting figure which may be thought of as some sensible portion of the sales dollar each hour of machine-running produces. It is a relative figure which need not be defined too rigorously here. Rather we shall treat several values, ranging from $2.00 to $8.00.

$(1 -$ *Percent Running Time*$)$: Loss imposed by our particular system of $m$, $r$ and $\lambda/\mu$.

We now have an expression that represents the cost of standby help and a cost of a loss of not utilizing our equipment 100 percent. Next, the percent Running Times shown in Tables 2 and 3 are substituted into this expression and Costs/Machine-Hour for various values of $R_M$ are determined. These data are presented in Tables 4 and 5.

Examination of these tables discloses interesting and valuable information concerning the manner in which the costs/machine-hour vary. In Table 4, for each $R_M$ chosen the use of three repairmen provides a least cost solution. When labor and machine costs are equal ($R_M$ = $2.00; $R_H$ = $2.00) the problem of machines waiting for service becomes less important. (Figure 3 is a graphic representation of the data in Table 4.)

TABLE 4

*Costs for System*

$\left(m = 20;\ \frac{\lambda}{\mu} = .1\right)$

| Repairmen $r$ | Cost/Machine hr ($) | | | |
|---|---|---|---|---|
| | $R_H$ = 2.00 | 2.00 | 2.00 | 2.00 |
| | $R_M$ = 8.00 | 6.00 | 4.00 | 2.00 |
| 2 | 1.46 | 1.15 | .83 | .51 |
| 3 | 1.11 | .91 | .70 | .50 |
| 4 | 1.14 | .96 | .77 | .58 |
| 5 | 1.23 | 1.05 | .86 | .68 |

TABLE 5

*Costs for System*

$\left(m = 30;\ \frac{\lambda}{\mu} = .1\right)$

| Repairmen $r$ | Cost/Machine hr ($) | | | |
|---|---|---|---|---|
| | $R_H$ = 2.00 | 2.00 | 2.00 | 2.00 |
| | $R_M$ = 8.00 | 6.00 | 4.00 | 2.00 |
| 3 | 1.32 | 1.04 | .76 | .48 |
| 4 | 1.14 | .91 | .70 | .48 |
| 5 | 1.08 | .89 | .71 | .51 |
| 6 | 1.13 | .95 | .77 | .58 |
| 7 | 1.19 | 1.01 | .83 | .65 |
| 8 | 1.26 | 1.07 | .90 | .71 |

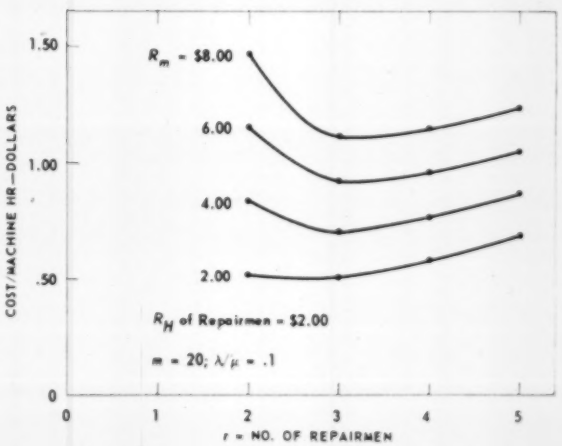


FIG. 3. Cost/Machine-Hr. vs No. Repairmen

For a given system of machines it is possible to arrive at criteria for determining the most economical number of workmen to assign to the group. Also if a safety factor is desired, an approximation of this cost can be made by merely looking at the cost for one additional serviceman. However, when this is done it should be remembered that greater idle-man time will result and should be expected.[4]

Comparing the minimum cost solutions found in Tables 4 and 5 for $R_M$ = \$8.00 it can be seen that the addition of two men to the crew—raising the number from 3 to 5—reduces the minimum servicing cost that may be realized from \$1.11 to \$1.08 machine-hour.

This fact leads to an important implication. It suggests that, other conditions being equivalent[5] savings may be achieved by organizing, where possible, larger groups responsible for a greater number of machines. In order to give a more comprehensive picture of the minimum cost solution varying with the size of the group of machines, Table 6 has been compiled and presented graphically as Figure 4.

To illustrate this point, in a situation where there are 40 machines and the decision to be made involves whether, (a) it would be better to assign 2 men to each of 4 groups of 10 machines; or (b) assign 6 men to the entire 40 machines. Looking in Table 6 the reader can see that both the 2-men and 6-men groups are minimum cost solutions for the machine group size. Further, solution (a) would require 8 men at a total cost of \$48.00/hour; solution (b) requires only 6 men and a total cost of \$42.00/hour. In this case the Expected Percent Running Time is increased from 90.0% to 90.65%.

The effect of the factors in footnote 5 should be evaluated before accepting these results. If these factors bear a direct relationship to the size of the machine group $m$, it is possible that Figure 4 could be adjusted to show the effect of such costs incurred in larger groups. This would indicate that some optimum group size exists and might be determined, since such costs would tend to increase as a function of $m$.

In summation, substantial economies may be found to exist by organizing in larger group sizes and the practice of assigning an optimum number of machines to a *single* operator might well be analyzed in the light of this discussion. Figure 4 gives an excellent indication of the magnitude of costs of such practice. In this regard it should be emphasized that while the example chosen to illustrate the method was one of maintenance repair, the method of analysis is applicable to many other types of work situations, one which will now be discussed.

TABLE 6

*Minimum Cost Solutions*

(Various Numbers of Machines, $m$; $\frac{\lambda}{\mu}$ = .1; $R_m$ = \$8.00)

| Machines $m$ | Solutions | | Expected Running Time, % |
|---|---|---|---|
| | \$ | $r$ | |
| 10 | 1.20 | 2 | 90.00 |
| 20 | 1.11 | 3 | 89.90 |
| 30 | 1.08 | 5 | 90.68 |
| 40 | 1.05 | 6 | 90.65 |
| 50 | 1.03 | 7 | 90.61 |
| 60 | 1.02 | 8 | 90.59 |
| 70 | 1.01 | 9 | 90.57 |
| 80 | 1.005 | 10 | 90.55 |
| 90 | 1.000 | 11 | 90.54 |
| 100 | .995 | 12 | 90.53 |

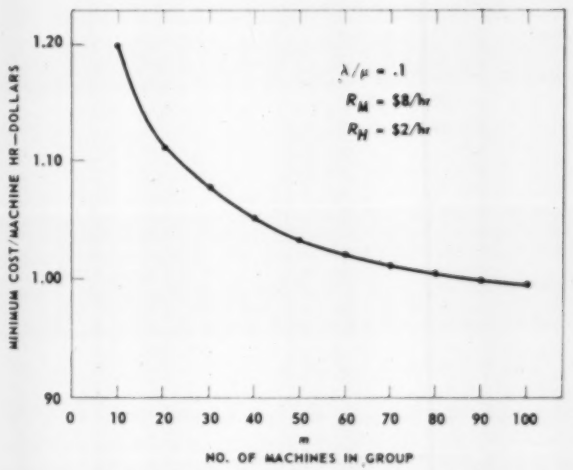


FIG. 4. Minimum Cost/Machine Hr. for Varying Size Groups of Machines

## Application to Organization Design

The objective of this section will be to demonstrate how the application of the methods discussed previously would be of assistance in evaluating different ways of organizing a work force in a company. To do this, it will be necessary to go back a few years and trace chronologically the changes actually made in developing an organization to its final form. The reader is warned that this example has been considerably modified at the request of the company involved.

[4] The average amount of idle time (for repairmen) which should result may also be calculated from the data in Table 1 by the following:

$$\sum_{n=0}^{r-1} (r - n) P_n$$

= *Expected Number of Repairmen Idle* at any given time.

This result, when divided by $r$—gives the Percent Idle Time Expected for each repairman. These values are generally considerably higher for minimum cost solutions than "common sense" may lead one to believe.

[5] Specifically that: (a) Longer distances of travel by the repairmen are not involved, or do not cause a significant change in the servicing rate; (b) Communications are equivalent; (c) Morale of larger groups is equivalent.

To the extent that these conditions *are* met, it is apparent that further savings are possible through reduced supervisory effort.

TABLE 7

*History of Organizational Changes*

| Step | Elapsed Time Organization In Effect (years) | Method of Organization | Organization | | Supervision | | Total Employees | Cell Running Time, % | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Men | Test Cells | Number | Position | | Actual | Theoretical |
| A | | Functional | 115–120 | | 1 | Chief Oper. | | | |
| | | | | | 1 | Chief Installer | — | | |
| | | | | | 1 | Chief Mechanic | | | |
| B | .5 | Crew | 8 | 4 stds | 4 | Foreman, each (16 cells) | 132 | | |
| C | 1.5 | Crew | .7 | 4 | 4 | Foreman, each (16 cells) | 116 | | |
| D | .5 | Crew | 6 | 4 | 4 | Foreman | 100 | .65 | .677 |
| E | | Crew | 24 | 16 | | | | | |
| F | .5 | Functional | 24 | 16 | 4 | Foreman | 100 | | .7302 |
| G | — | Functional | 84 | 64 | 2 | Foreman | 89 | .74 | .7363 |
| | | | | | 3 | Prod. Control | | | |

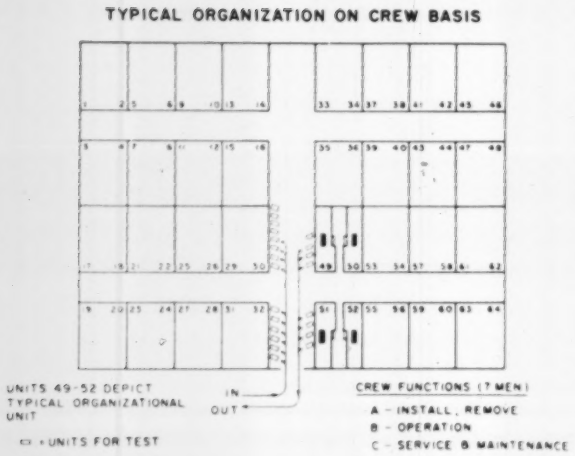


FIG. 5. Typical Organization on Crew Basis

Figure 5 depicts the layout of an engine-testing department. Individual units of work in this department may be imagined as beginning at the float of incoming engines shown and ending when the engine has completed its test and has been placed in the OUT float shown. The essential tasks in this department are: (a) *Installation, Removal:* engines are transported from the IN float and installed on one of the 64 test blocks shown. Upon completion of a prescribed test, the engine must be removed and returned to the OUT float. Two men are required in a crew for this task. (b) *Operation:* Tests of varying length are prescribed for the engines. A test operator runs the engine during these tests and records pertinent data concerning their performance. (c) *Service and Maintenance:* occasional failures or need for adjustment occur during testing, specialized help is needed for this task.

During a period of three years arguments centered around whether a *functional* organization or a *crew* organization could best discharge these tasks. Another pertinent question concerned how many men were needed for either task. The functional method may be defined as organizing the work force by the three tasks, with a foreman or chief over each of these three functions; he makes assignments to cells where needed. The crew organization is made up of individuals who presumably are capable of doing all three required tasks. Each crew was to be given 4 stands (such as 49–52 in Figure 5) for which they were responsible for all work. As the reader can well imagine there are a lot of pros and cons for either approach and it will not be to our interest to attempt a detailed discussion. However, it is of interest to us to know of the history and timing of the decisions that were made.

Table 7 attempts to list the major aspects of interest in these decisions. In 3 years a full cycle from functional to crew to functional method of organization occurred with a considerable reduction in manpower required. Arguments which initiated the Crew Basis (Step B) centered around better morale, better training for fairly high turnover being experienced, and hoped-for reductions in manpower by eliminating the time lags of each Functional Chief in dispatching his men. This dispatching was all done by leg work on the part of each chief.

As time went on, it became evident that there was much idle-man time; consequently, changes to Steps C and D were made in the interests of economy. However, as soon as Step D was made it became obvious that "interference" occurred frequently in a group of 4 cells when 2 or more engines finished a test at about the same time. This was a serious factor and could only be accommodated by each foreman considering all 16 of his test cells as one large crew. This had the effect of reducing the motivation caused by crew competition.

This led gradually to a trend towards having some of the men specialize in one or another of the functions until Step F was essentially in effect. When the impact of this evolution was realized and studied by line management, it was decided to centralize the dispatching of crews into one office, to install a board showing the status of each cell in the office, and finally to install telephones to each group of 2 cells to provide instantaneous communication. Thus, individuals of any one task category would be given as-

## TABLE 8

*Expected % Units Running*

$\lambda/\mu = .01$

| No. of Repair Units $r$ | $m$ = No. of Units to be Serviced | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 1 | 98.81 | 98.64 | 98.5 | 98.18 | 97.81 | 97.27 | 96.44 | 95.09 | |
| 2 | 99.01 | 98.99 | 98.98 | 98.96 | 98.93 | 98.89 | 98.85 | 98.79 | 98.72 |
| 3 | 99.01 | 99.01 | 99.01 | 99.01 | 99.01 | 99.00 | 99.00 | 98.99 | 98.99 |
| 4 | | 99.01 | 99.01 | 99.01 | 99.01 | 99.01 | 99.01 | 99.01 | 99.01 |
| 5 | | | | | | 99.01 | 99.01 | 99.01 | 99.01 |

## TABLE 9

*Expected % Units Running*

$\lambda/\mu = .05$

| No. of Repair Units $r$ | $m$ = No. of Units to be Serviced | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 1 | 92.96 | 90.30 | 85.77 | | | | | | | | |
| 2 | 95.06 | 94.84 | 94.38 | 92.62 | 88.48 | | | | | | |
| 3 | 95.24 | 95.21 | 95.18 | 94.92 | | 92.03 | 90.74 | | | | |
| 4 | | | 95.24 | 95.24 | 95.09 | | 94.70 | 93.19 | 90.92 | | |
| 5 | | | | 95.24 | 95.21 | 95.16 | 95.04 | | 94.29 | 93.33 | 91.52 |
| 6 | | | | 95.24 | 95.24 | | | 95.13 | 94.99 | 94.74 | 94.28 |
| 7 | | | | | 95.24 | 95.24 | 95.23 | | | 95.10 | 94.96 |
| 8 | | | | | 95.24 | 95.24 | 95.24 | 95.23 | 95.22 | 95.20 | 95.15 |
| 9 | | | | | | 95.24 | 95.24 | 95.24 | 95.24 | 95.24 | |
| 10 | | | | | | | 95.24 | 95.24 | 95.24 | 95.24 | 95.23 |
| 11 | | | | | | | | | | | |
| 12 | | | | | | | | | | | 95.24 |

## TABLE 10

*Expected % Units Running*

$\lambda/\mu = .10$

| No. of Repair Units $r$ | $m$ = No. of Units to be Serviced | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 1 | 89.38 | 87.53 | 84.91 | 81.51 | | | | | | | | | | |
| 2 | 90.91 | 90.74 | 90.43 | 90.00 | 87.99 | 84.18 | | | | | | | | |
| 3 | 90.91 | 90.91 | 90.91 | 90.91 | 90.57 | 89.90 | 85.94 | | | | | | | |
| 4 | | 90.91 | | | 90.87 | | | 86.89 | | | | | | |
| 5 | | | | | | 90.89 | 90.69 | | 87.49 | | | | | |
| 6 | | | | | | | 90.87 | 90.65 | | 87.91 | | | | |
| 7 | | | | | | | 90.91 | | 90.62 | | 88.22 | | | |
| 8 | | | | | | | 90.91 | 90.89 | | 90.59 | 89.97 | 88.48 | | |
| 9 | | | | | | | 90.91 | 90.91 | 90.89 | | 90.57 | | 88.69 | |
| 10 | | | | | | | 90.91 | 90.91 | 90.90 | 90.88 | 90.79 | 90.56 | 90.02 | 88.86 |
| 11 | | | | | | | | | 90.91 | 90.90 | 90.87 | | | |
| 12 | | | | | | | | | 90.91 | 90.91 | 90.90 | 90.86 | 90.77 | 90.55 |
| 13 | | | | | | | | | 90.91 | 90.91 | 90.91 | 90.90 | | |
| 14 | | | | | | | | | | 90.91 | | 90.91 | | 90.85 |
| 15 | | | | | | | | | | | | 90.91 | 90.90 | 90.88 |
| 16 | | | | | | | | | | | | | 90.91 | |
| 17 | | | | | | | | | | | | | 90.91 | |
| 18 | | | | | | | | | | | | | 90.91 | |
| 20 | | | | | | | | | | | | 90.91 | | 90.91 |

## TABLE 11

*Expected % Units Running*

$\lambda/\mu = .15$

| No. of Repair Units $r$ | $m$ = No. of Units to be Serviced | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 1 | 84.19 | 80.20 | | | | | | | | | | | | |
| 2 | 86.83 | 86.44 | 85.62 | 84.34 | | | | | | | | | | |
| 3 | 86.96 | 86.96 | 86.83 | 86.70 | 85.54 | 82.64 | | | | | | | | |
| 4 | | 86.96 | 86.96 | 86.93 | 86.75 | 86.08 | 81.07 | | | | | | | |
| 5 | | | | 86.96 | 86.93 | 86.78 | | | | | | | | |
| 6 | | | | | 86.96 | 86.93 | 86.52 | 84.50 | | | | | | |
| 7 | | | | | | 86.95 | | | 83.60 | | | | | |
| 8 | | | | | | | 86.94 | 86.70 | 85.72 | | | | | |
| 9 | | | | | | | 86.95 | | | 85.21 | | | | |
| 10 | | | | | | | 86.96 | 86.93 | 86.80 | 86.26 | 84.66 | | | |
| 11 | | | | | | | | 86.95 | 86.90 | | | 84.06 | | |
| 12 | | | | | | | | 86.96 | 86.94 | | 86.54 | 85.62 | 83.43 | |
| 13 | | | | | | | | 86.96 | 86.95 | | | | 85.54 | |
| 14 | | | | | | | | | 86.95 | | 86.89 | 86.69 | 86.16 | 84.94 |
| 15 | | | | | | | | | 86.96 | 86.95 | 86.93 | 86.84 | 86.57 | 85.90 |
| 16 | | | | | | | | | | 86.96 | 86.95 | | | |
| 17 | | | | | | | | | | 86.96 | 86.95 | | | |
| 18 | | | | | | | | | | | 86.96 | | | |
| 19 | | | | | | | | | | | 86.96 | | | |
| 20 | | | | | | | | | | | 86.96 | 86.96 | 86.95 | 86.93 |
| 25 | | | | | | | | | | | | 86.96 | 86.96 | 86.96 |
| 30 | | | | | | | | | | | | | | 86.96 |
| 35 | | | | | | | | | | | | | | 86.96 |

## TABLE 12

*Expected % Units Running*

$\lambda/\mu = .2$

| No. of Repair Units $r$ | $m$ = No. of Units to be Serviced | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 1 | 70.04 | | | | | | | | | | | | | |
| 2 | 83.12 | 82.31 | 80.69 | 78.18 | | | | | | | | | | |
| 3 | 83.33 | 83.28 | 83.10 | 82.66 | 79.75 | | | | | | | | | |
| 4 | | | 83.33 | 83.26 | 82.64 | 80.56 | | | | | | | | |
| 5 | | | | 83.33 | 83.21 | 82.67 | | | | | | | | |
| 6 | | | | | 83.32 | 83.19 | 81.41 | | | | | | | |
| 7 | | | | | | 83.30 | | | | | | | | |
| 8 | | | | | | 83.33 | 83.15 | 81.86 | | | | | | |
| 9 | | | | | | | 83.28 | | 79.82 | | | | | |
| 10 | | | | | | | 83.32 | | 82.16 | 78.83 | | | | |
| 11 | | | | | | | 83.33 | 83.27 | | 81.22 | | | | |
| 12 | | | | | | | | 83.31 | | 82.38 | 79.95 | | | |
| 13 | | | | | | | | 83.33 | | 82.91 | 81.84 | | | |
| 14 | | | | | | | | 83.33 | | | 82.53 | 80.79 | | |
| 15 | | | | | | | 83.33 | 83.33 | 83.32 | 83.29 | 82.92 | 81.99 | 79.69 | |
| 16 | | | | | | | | | 83.33 | | | 82.66 | 81.24 | |
| 17 | | | | | | | | | 83.33 | | | | 82.22 | 79.94 |
| 18 | | | | | | | | | 83.33 | | | | 82.76 | 79.90 |
| 19 | | | | | | | | | 83.33 | | | | | 82.40 |
| 20 | | | | | | | | | | 83.33 | 83.33 | 83.31 | 83.19 | 82.98 |
| 25 | | | | | | | | | | | 83.33 | 83.33 | 83.33 | 83.32 |
| 30 | | | | | | | | | | 83.33 | 83.33 | 83.33 | 83.33 | 83.33 |
| 35 | | | | | | | | | | | | 83.33 | | 83.33 |

signments from the central office either in advance or would be one-call at a waiting room. This gradually led to a work force of only 89 and an increase of about 9 percent in test cell utilization—a term analogous to Percent Running Time used earlier in the article. Note that two foremen were gradually replaced by a 3-man Production Control Staff. This was all done on the basis of letting normal turnover effect the reduction and was done with a minimum of confusion.

It is interesting to note that only $6,000–$10,000 was spent in making the final change. It is also interesting to speculate in regard to what might have been saved in the way of manpower costs if the last mode of organization could have been agreed upon earlier in the three year period described. Counting all costs (telephone, etc.), if the decision were made and implemented without lag, to have been effective at Step B approximately $366,000 might have been saved; if the decision were to have been made at Step C, $267,500; finally at Step D, approximately $53,000. Certainly potentially great savings are possible when the time to arrive at such decisions can be materially reduced. This leads to speculating on what would have happened if an analysis of the basic queueing problem had been made at Step A involving the methods described.

It has been possible to obtain data from the period indicated. These data permit calculation of estimates for the ratios of Task A (Installation-Removal) and Task C (Servicing to the Running Time) for each cell (Task B). These "servicing-factors" were quite close to .2 and .1 respectively. Tests of the distributions for the Expected Times for these Tasks were only partially satisfactory. However, with reference to the unpublished work of Clark, $\sigma_E$ was found to be 1.5 times the 1 $\mu$ for Task A and nearly 3 times the 1 $\mu$ for Task C. Consequently, use of tables included at the end of this paper was deemed appropriate.

Analysis indicated that manpower requirements were as follows.

| | Step F (Table 7) Four 16 Cell pools | | Step G (Table 7) One 64 Cell pool | |
|---|---|---|---|---|
| A | Installers | 8 | Installers | 28 |
| B | Operators | 13 | Operators | 45 |
| C | Mechanics | 3 | Mechanics | 8 |
| | | 24 | | 81 |
| | Total for 4 Groups = 96 | | | |

These results do not include the foremen; they show that the method of organization decided by the company over a three-year period is quite close to that analytically derived in a period of time which might be estimated as one man-month.

Reference to Table 7 also shows that organizing the test cells in 64 units rather than 16 will give an estimated rise in Percent Cell Running Time from 73.02 to 73.63 at the same time permitting manpower to be reduced from 96 to 81 (theoretical) or 96 to 84 (actual). Even when the continuing costs of the telephones, production control clerks are included, a saving of $53,000 per year is realizable. Cost of installation, of course, must be subtracted from the first year operation.

## Conclusions

While much of this example smacks of hindsight, the author is of the opinion that a couple of pertinent points may be made:

(1) An organization which is determined by natural evolution involving line management decisions may take an exceedingly long time to arrive at its most efficient structure. Analysis of the organization in the manner herein discussed should materially reduce the time in reaching this optimum design.

(2) In suitable types of organization, the queueing-theory approach appears to give a good approximation (for at least the example related) and is also of real value in obtaining an insight into the way different factors influence the efficiency of the system. Study of such problem areas by development of appropriate difference equations, or by Monte Carlo methods offers a quite fertile field for today's industrial engineer.

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# Applicability of Standard Data for Production Scheduling

**By Alan J. Rowe**

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Production scheduling is concerned with assigning given jobs to specific machines in a time sequence. Since the assignment of jobs is predicated on a knowledge of the time to perform various operations, time standards form an integral part of the scheduling procedure. Thus, in part, the success of a scheduling method will depend upon how well the processing times can be predicted. In many instances, production scheduling is concerned with products which have not previously been manufactured, (this is common in the job shop). Under these circumstances, standard data provides the only available basis for estimating processing time. Where there are engineering or design changes, there is the need for new time estimates. In the absence of standard data, these activities must be based on experience or guesses. Under some circumstances, experience is an adequate measure; however, in order to obtain maximum usefulness from mathematical methods of production scheduling, it will be necessary to have reliable and valid time standards. If the data used for the standards are poor, the results of a scheduling procedure could be vitiated. The usefulness of standard data has been demonstrated by its extended application to industrial problems.

In order to predict manufacturing processing time, standards must be reliable and valid. Reliability refers to the consistency of the time standards, and validity refers to the same absolute effort requirements for a given job regardless of where it is performed. The consistency of time standards has received considerable attention from research workers, but the effort requirements are subject to management-worker negotiations rather than work measurement experimentation. Thus, a basic standard can be defined as one which represents a norm of performance rather than actual performance. This norm should be attainable by qualified workers during actual working periods. The norm or basic standard time will not precisely predict individual performance time, but the actual average time which is spent performing a given task would approach the standard in the long run.

Standard data is a compilation of the actual average times for performing particular elements of work. Some standard data has been developed synthetically in the laboratory by duplication of factory work requirements. Since this latter data is gathered under controlled conditions, it can more easily separate the variables under consideration. However, a careful comparison of the various available systems of standard data would be desirable to ascertain their consistency with one another.

A basic hypothesis in standard data is that work can be subdivided into basic elements which can be recombined in any desired sequence. It is assumed that the total time to perform a given element is independent of the sequences in which it occurs. This has led to a major criticism of standard data, namely that it may not be possible to treat the elements of motion as independent building blocks in order to predict the time to perform a given task; that is, that elemental motions are generally dependent and the usual procedure of treating them as independent will give rise to errors in predicting the expected time to perform a given sequence. This paper will be concerned with a preliminary analysis of standard data and the problem of additivity of elements.

The problem of dependence of motions requires some clarification. There are two kinds of dependence. One type of dependence refers to the increase or decrease in time to perform a given motion depending on what particular motion precedes or follows the given motion. The question is, are elements of motion independent units which can be shifted around at will, or are they closely linked to the surrounding motions? If elements of motion are truly independent, they can be added in any desired sequence. This leads to the question, are elements of motion as currently defined by standard data systems adequately specified so that they can be treated as though they were independent? This implies that the grouping of motions into categories could be done in such a manner that the preceding and following motions would be stratified so as to minimize the errors due to adding elements. Stratifying or classifying always involves an aggregation of information which in turn means a loss of information. The appropriateness of the groups depends on whether they are homogenous or the seriousness of the loss of information and the purpose for which the data are to be used. We can think of this in terms of what probability or confidence level are we willing to accept in considering the classification as describing a unique population. The risk of error which we are willing to accept depends on the economic cost of differentiating one group from another, and the importance of the data.

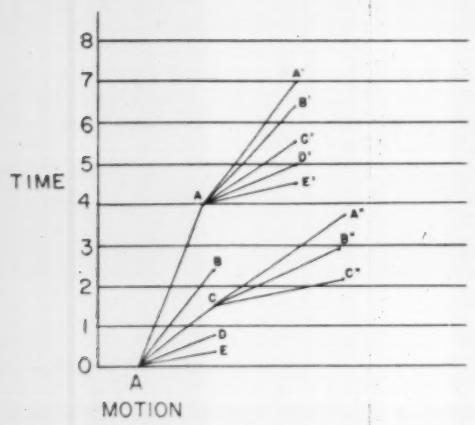


FIG. 1

Referring to Figure 1, we can graphically see the problem of grouping motions. For any given motion "*A*" there are a large number of possible following motions (*a*, *b*, *c*, *d*, *e*, for example), and the time to complete the combined motions (*Aa* or *Ad*, etc.) will depend on the particular set. This can be extended to include three or more motions. The diagram shows that there is a vast number of possible motion combinations. Since it is not desirable to enumerate all such possible combinations, it is necessary to group motions. For example, motion *A* followed by *d* or *e* might be considered as one group. The motions following "*A*" can be stratified into any number of groups. Then we have to determine whether these classes or groups are adequate for predicting standard times. Fruitful research can be undertaken to determine what grouping, if any, will provide standard data which will have the property of negligible errors when the elemental motions are added in any sequence. The errors could be considered negligible when the aggregate absolute amount does not exceed two or three percent of the final time standard.

Associated with the problem of grouping or aggregation, are the problems of individual differences. Thus, for each motion there is a mean or average time which is a parameter of a given population rather than the exact value that could be expected from any particular individual's performance. There are a number of factors which influence the performance time for elemental motions. For example, there are differences in physiological capacities, psychological factors such as motivation, learning, etc., and environmental conditions. Thus, added to the problem of the grouping or classifying procedure is the question of the suitability of using average time values as the basis for establishing standard times for individuals. Presumably, selection procedures in industry provide a reasonably homogeneous population so that the use of averages is suitable.

The second type of dependence is a statistical or probability dependence. Whereas the first type of dependence was concerned with predicting the time for performing work depending on *which* motion preceded and followed, statistical dependence is concerned with predicting the time for given elements of work based on the *time* which specific individuals take for adjoining elements. Statistical dependence in this instance can be measured by the correlation between successive elements of work for a given individual. That is, we might find the average time for performing a particular motion varies depending on the time for the following motion. However, if elemental motions are interdependent, an important question is how much error will result from predicting the expected performance time when the dependence is ignored. The magnitude of the error will be a function of the degree of dependence, where the dependence refers to the correlation or covariance among the elements. Where the correlation is low (i.e., equal to .1 or .2), it is clear that the assumption of independence will lead to a negligible error in prediction (less than two or three percent).

Where elements are statistically *independent*, it is possible to predict the expected value of any given element with no knowledge of the others. When elements are correlated, they are dependent in a probability sense, and their expected values are related by a mathematical function. Further, where chance variables are uncorrelated, they may or may not be statistically independent. For a normal distribution, uncorrelated also means statistical independence. Statistical independence between variables $x$ and $y$ is defined as the case in which the conditional density function $f(x \mid y)$ does not involve $y$. Correlation, or dependence in the probability sense, can be explained by stating that the error in prediction of one of the factors will be reduced if the information about the factors is properly used. The percent error introduced by ignoring the correlation, and the way in which various expected errors depend upon the degree of correlation are shown later in this paper.

Statistical dependence is important primarily where one desires an estimate of the variability of the expected values. As far as the expected values themselves (arithmetic means) are concerned, it is a sufficient condition (statistically) that the elements be random variables in order to predict their mean values accurately; since the mean value of a sum of random variables is equal to the sum of the mean values of the variables themselves. This is true whether or not the variables are statistically dependent or independent. Thus, if there are three variable $x$, $y$, and $z$, and these are random variables, with a joint density function $f(x, y, z)$, then the expected value of their sum $E(x + y + z) = E(x) + E(y) + E(z)$. The significance of this theorem in standard data is that the mean time for a motion pattern can be described either as the mean time for the entire motion or the sum of the average time values for the component elements, as long as these elements are random variables. Thus, the problem is: are

the elemental motions subdivided in such a manner that their time-values are random variables?

Since this is an important aspect of the entire problem, it would seem worthwhile to discuss this question of random variables further. A random variable is a numerical values variable defined on a sample space. This concept may be associated with physical experiments by showing that the outcome of a series of events depends on chance. As an example, the number of points on a sample space for the tossing of two dies is 36 (considering the $x$ axis as 6 points and the $y$ axis as the other 6 and the sample space as the possible permutation of these two), where the random variable $x$ is defined as the sum of the numbers appearing on the individual dies when tossed; and where this sum assumes values from 2 to 12. A function $f(x)$ which gives the probability that a random variable $x$ will have any particular value in its range is called the frequency function of the random variable $x$. This definition can be extended to more than one variable by a joint frequency or density function. This extension is of interest for the purpose of analysis of motion patterns since in general these are joint density functions. Any particular set of numbers may or may not be random depending on the manner in which they were generated. Thus, randomness is not a property of the numbers but of the process from which they were obtained. If numbers come from a process which is believed to be random, and the numbers meet various tests for randomness, they are considered to be random numbers.

Statistical dependence, or correlation, does not present the major difficulty in standard data since dependence can be ignored in estimating the mean performance time where the standard data elements are defined so that the time values are random variables. The important problem is the question of the dependence due to stratification. This question can only be answered by experimentally showing whether the current groupings are satisfactory.

Where data is available on the correlation between two variables it is possible to estimate the errors of prediction. These errors can be classified into two groups, those associated with errors in prediction of the performance time, and errors in prediction of the variance of the variables. It was noted previously that the mean time for the performance of elements could be predicted providing they were random variables. However, it might be desirable to obtain a more precise estimate of the performance time than the average. That is, knowing that two elements are correlated, it is possible to more accurately predict the performance time of the second motion providing the first is known and the correlation. This increase in the accuracy of prediction can be measured as a function of the degree of correlation. This would only be applicable in individual circumstances where the correlation had been estimated from a sample study. Since there is no measure of the correlation among elements for all kinds of work and for all types of people, this could not be generalized beyond saying that, if the correlations were known the following analysis would indicate the error which would have been introduced into standard data by ignoring the correlation.

In order to estimate the magnitude of the error involved in ignoring correlation (which is essentially what current standard data systems do) we should define the total error (total variance) as consisting of two parts, the variance due to correlation and the variance due to random or non-assignable causes.

If

$\sigma_y^2$ = total variance

$\sigma_{yc}^2$ = variance due to correlation

$\sigma_{ys}^2$ = variance due to random causes

then

$$\sigma_y^2 = \sigma_{yc}^2 + \sigma_{ys}^2$$

The correlation coefficient "$r$" is defined as the square root of the ratio of the variance due to correlation with the total variance

$$r = \sqrt{\frac{\sigma_{yc}^2}{\sigma_y^2}} = \sqrt{\frac{1 - \sigma_{ys}^2}{\sigma_y^2}}$$

Another interpretation of "$r$" is the ratio of the square root of the covariance of two sets of observations to the geometric mean of the separate variances.

If we have sets of observations $x$ and $y$, their covariance is $\sigma_{xy}^2$, and the separate variances are $\sigma_x^2$ and $\sigma_y^2$; then

$$r = \sqrt{\frac{\sigma_{xy}^2}{(\sigma_x^2)(\sigma_y^2)}}.$$

If $r^2 = \dfrac{1 - \sigma_{ys}^2}{\sigma_y^2}$, then $\sigma_{ys} = \sigma_y\sqrt{1 - r^2}$, which is called the standard error estimate. Thus, $\sigma_{ys}$ can be expressed in terms of the total variance $\sigma_y$ and the coefficients of correlation "$r$". If any two of the three parameters are available, then the third can be calculated. The factor $\sqrt{1 - r^2}$ is used as a measure of the error of the prediction. The efficiency of forecasting is described as $1 - \sqrt{1 - r^2}$ which indicates how much better the prediction would be than a random guess (no knowledge of $r$) as a function of "$r$".

| $r$ | $1 - \sqrt{1 - r^2}$ |
|---|---|
| 1 | 1.00 |
| .9 | .56 |
| .8 | .40 |
| .7 | .29 |
| .6 | .20 |
| .5 | .13 |
| .4 | .08 |
| .3 | .05 |
| .2 | .02 |
| .1 | .005 |
| 0 | .00 |

For example, knowing that $\sigma_y^2 = \sigma_{yc}^2 + \sigma_{ys}^2$, and given that $\sigma_{yc}^2 = \sigma_y^2$, there would be no random error $\sigma_{ys}^2$ and $r$

would = 1.00, then $1 - \sqrt{1 - r^2} = 1.00$, indicating a perfect prediction where there is perfect correlation. Let us consider the case where $\sigma^2_{yc} = \sigma^2_{ys}$, then

$$\sigma^2_y = 2\sigma^2_{yc} \text{ or } r = \frac{\sigma^2_{yc}}{\sigma^2_y} = \frac{\frac{\sigma^2_y}{2}}{\sigma^2_y} = \frac{1}{2}$$

In this instance the efficiency of forecasting is:
$\eta = 1 - \sqrt{1 - .5^2} = 1 - \sqrt{.75} = .134$, which indicates that the prediction based on information due to correlation has a probability of being 13 percent better than a pure guess. At the other extreme, if $\sigma^2_y = \sigma^2_{ys}$, the correlation is zero, and all the error can be attributed to random causes.

Still another problem is the estimate of the variance of two or more elements as a function of the correlation. In order to estimate the error of the variance when ignoring correlation, we consider the general case of the total variances: $\sigma^2_T = \sigma^2_x + \sigma^2_y + 2\sigma_{xy} = \sigma^2_x + \sigma^2_y + 2r_{xy}\,\sigma_x\,\sigma_y$, where there are two variables $x$ and $y$ with $\sigma^2_x$ and $\sigma^2_y$ and correlation $r_{xy}$.

If $\sigma_1 = \sigma_2$ then $\sigma^2_T = 2\sigma^2_1 + 2r_{12}\,\sigma^2_1$. The error in $\sigma^2_T$ ignoring correlation is:

$$E = \frac{2r_{xy}\,\sigma^2_x}{2\sigma^2_x + 2r_{xy}\,\sigma^2_x} = \frac{r_{xy}\,\sigma^2_x}{\sigma^2_x + r_{xy}\,\sigma^2_x} = \frac{r_{xy}}{1 + r_{xy}}$$

thus for $r_{xy} = 1$, the error in ignoring correlation when estimating the total variance is 50 percent.

for $r_{xy} = .5$, the error is $33\frac{1}{3}$ percent.
for $r_{xy} = .2$, the error is 25 percent.
for $r_{xy} = .1$, the error is 11 percent.
for $r_{xy} = 0$, the error is 0 percent.

Another consideration is the sampling error of "r". Thus it is necessary to determine whether "r" is significant as a function of the sample size. Since in general $x \neq y$, that is, the two standard deviations differ by some amount $\epsilon$.

$$\text{then } \sigma^2_T = (\sigma_y + \epsilon)^2 + \sigma^2_y + 2r_{xy}\,\sigma_y\,(\sigma_y + \epsilon)$$

$$= \sigma^2_y + 2\sigma_y + \epsilon^2 + \sigma^2_y + 2r_{xy}\,[\sigma^2_y + \sigma_y\,\epsilon]$$

$$= 2\sigma^2_y + 2\sigma_y + \epsilon^2 + 2r_{xy}\,\sigma^2_y + 2r_{xy}\,\sigma_y\,\epsilon$$

The error in assuming $r_x = 0$ is then for the general case:

$$E = \frac{2r_{xy}\,\sigma^2_y + 2r_{xy}\,\sigma y\cdot\epsilon}{2\sigma^2_y + 2\sigma y\cdot\epsilon + \epsilon^2 + 2r_{xy}\,\sigma^2_y + 2r_{xy}\,\sigma y\cdot\epsilon}$$

When $r_{xy}$ is 1.00 the error in assuming it is zero, can be evaluated for the case where $\sigma_x \to \sigma_y$, and $\epsilon \to 0$. In the limit, $E = \frac{1}{2} = 50$ percent (which was shown previously).

If we let $\sigma_2 = 1$, and $r_{12} = 1$
then

$$E = \frac{4}{4 + 4 + 1} = \frac{4}{9}$$

for $\sigma_2 = 2$ and $r_{12} = 1$

$$E = \frac{12}{16 + 8 + 1} = \frac{12}{25}$$

Other examples can be used to show the error of predicting variances as a function of the correlation and the relative magnitude of the variances. In the example shown, the maximum error is in the order of 50 percent depending on the two variances. This error reduces rapidly as the correlation is reduced. It must be remembered that the above refers to the error of predicting the range of variation and not the error of predicting the expected or average times.

In summary, it has been the purpose of this paper to consider the problem of whether the mean time for the performance of elements of a motion pattern can be added to estimate the expected mean time for any given set of elements. Where the elements are dependent, the degree of dependence, or the correlation may be considered in order to estimate the error of prediction of the mean time (efficiency of forecasting) and to determine the error of neglecting the correlation on the estimate of the total variance. In production scheduling usage, the estimate of the mean times is the current problem rather than the estimate of the variance.

As was indicated, the problem of statistical dependence is not the important one at this time; since, if elemental motions are random variables, then they can be added together to obtain an estimate of the mean performance time whether or not the elemental motions are dependent. The important problem confronting standard data is the question of whether the classification of motions as currently defined by various systems is suitable for predicting standard times.

Further research should be fruitful in:

1. Determining whether elemental motions in psychomotor task can be considered to be random variables.
2. Obtaining estimates of the dependence of elemental motions.
3. Determining the appropriateness of current standard data classifications in view of the theoretical considerations.
4. Finding estimates of the variances of the elemental motion data.
5. Evaluating the magnitude of the absolute errors involved in using standard data as currently defined.


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# Research in the American Institute of Industrial Engineers, Inc.

**By Andrew Schultz, Jr.**

*Professor in Charge, Department of Industrial and Engineering Administration, Cornell University*
*Director of Research, AIIE*

At best, the formulation of a research program and policy for a professional society is not an easy job. To do so for an organization as young and ambitious as the American Institute of Industrial Engineers in today's dynamic and fast-unfolding field of Industrial Engineering is even more difficult. To be acceptable, such a program must meet long-range needs of the organization and also be compatible with probable developments in the fields of research involved. This means that the detailed program must, in its inception and execution, constantly consider two viewpoints—that of the organization and that of those doing the research. If sight of either one is lost, the program becomes irrelevant or sterile.

This problem is implicitly recognized in the AIIE Constitution by the phrasing of the purposes of the Institute. The third of these is "To encourage and assist education and research in areas of interest to the industrial engineer". The fourth is: "To promote the interchange of ideas and information among members of the industrial engineering profession". Both of these purposes should influence any attempt to define a research program for the organization.

The immediate problem is to outline a program which, within the current organizational and financial structure of the AIIE, can most effectively achieve the objectives. These are the encouragement of and assistance to research in areas of interest to industrial engineers and the promotion of the interchange of ideas and information among those members of the profession primarily interested in research. Obviously, anything done to promote the interchange of ideas and information with respect to research by members of the profession will aid and encourage such research. With recognition of this secondary objective but with devotion to the primary one, the following program is outlined.

## Types of Research

To aid and encourage research in the area is a broad rather than a narrow objective. Definition of those areas of interest to the industrial engineer is a continuous process which is taking place in the many different articles published in this Journal, and it is not proposed to discuss them here. On the other hand, definition or limitation of the term, research, is necessary. It has been used in writing and discussion by members of the Institute with an extremely broad connotation, and it is intended to follow this precedent here. It is proposed that the proper objective is to aid and encourage research of three general types. These are: (1) basic or fundamental research in specialized fields of importance to industrial engineers; (2) the development of new analytical techniques which involve the application of the results of research in many areas, some of which may not necessarily be of specialized importance to industrial engineers; and (3) the development of new or improved methods of synthesis. These are discussed in more detail below.

Certain areas of fundamental research are directly related to industrial engineering and, in some instances, peculiarly so. Some aspects of work measurement fall in this category; and while both industrial psychologists and industrial engineers have a direct interest in much of this research, such topics as levelling or rating investigations are of peculiar concern to the engineer. Other areas of research are less directly related but are rather general in their application. Examples of this are some of the results of mathematical and statistical research which have broad fields of application other than uses in the Quality Control, Sampling Inspection, Estimating, or Production and Cost Control procedures of industrial engineering. Research in areas of logic and communication theory which leads to engineering research in electronic equipment results, in turn, in computational and data processing equipment of direct concern to industrial engineering, as well as to other engineering and scientific disciplines.

From the few examples given, it can be seen that research in many other areas has a bearing on industrial engineering. Aid and encouragement in specific areas not previously deemed directly related to industrial engineering must be considered, as well as that offered for more obvious needs.

The development of new analytical techniques of importance to the profession generally comes about as the result of basic research progress. The benefits of such developments are realized more rapidly to the extent that the recognition of the need is combined with knowledge of the fundamental research and the area of application. Certainly, this organization can render a service by attempting to expedite such developments. The long time-lag between basic research and technique research and between technique development and application is well illustrated by statistical developments in the field of sampling inspection, which were founded on research done long before and not broadly applied for a decade. Basic research in mathematics and statistics, in psychology;

applied research in electrical engineering; and research in many other fields is currently taking place and is furnishing the basis for new industrial engineering techniques. In the field of production control alone, certainly of interest to industrial engineers, completely new concepts are developing as a result of such research.

The last category of research listed is of pressing interest to the industrial engineer; since it is perhaps most closely related to the engineer and his problems. It is the type of research that results in the development of new techniques of synthesis. These developments are related to the analytical ones discussed above and frequently stem from them. Some of these methods of synthesis may find application in areas other than industrial engineering. Examples of these are some of the servo-mechanism concepts which are used in design not only of electronic control systems but have application in the synthesis of inventory control systems and in automated production systems—both of concern to the industrial engineer. Other synthesis techniques, such as the refined line-balancing techniques, are of peculiar interest to industrial engineers. The concern of the industrial engineer with plant design and procedures specification, the concern with materials handling methods and automation, and many other trends discernible in the literature point up the need for absorption and refinement of the new conceptions emerging from basic research currently in progress with the ultimate objective of improvement of our methods of synthesis.

A common tendency in industry and among practicing industrial engineers is to deplore many of the new developments as being too "long-hair" or theoretical. Most individuals who have done research on some of the problems mentioned have had the experience of having their work so criticized. Therefore, it must be emphasized that if it is research, it is new; it is usually difficult to assimilate; and time is a factor in both the successful execution of the research and in the refinement of any practicable techniques of synthesis and analysis. Research, in general, is not easy but is usually difficult, and the interpretation of any good research for the practicing engineer is also difficult. Recognition of the truth in these statements is essential before a workable program can be developed or executed by the AIIE.

## The Problems

There are a number of problems associated with the successful completion of a program of research for the organization. One of these is the important question of means of obtaining broader recognition among industrial engineers not only of the need for research, but also of what good research is and of its value to the profession. Perhaps the answer to this problem may lie, in part, in the availability of good publications and access to a publication medium, which would make it possible for interested persons to keep up to date. In addition, the availability of a medium in which to announce new studies and results and of a forum for discussion of current problems of research will help.

It is evident that relatively few industrial corporations do any significant research in the area and that few of those that do have encouraged publications reporting results obtained. Some of our large corporations have been most culpable in this regard. Naturally there are problems in such publication from the corporate viewpoint, but they are not insurmountable, and more inclination on the part of industrial engineers to publish such results would be beneficial. This is, of course, another facet in the development of the true professional attitude.

The proper form of the organization charged with the aid and encouragement of research is another important problem in the planning stages. It is essential that considerable breadth of knowledge of specialized and general areas of research be represented, along with adequate ability and experience, to foresee and understand the needs of the industrial engineer. A satisfactory blending of theoretical concepts and knowledge of reality is necessary. Most important, the organization must be able to pursue its ends with great tact; for every industrial engineer seems to have his own special problems, ideas, peeves, and areas in which he would like more research. A program that will be worthwhile must be based on the long range viewpoint, flexible enough to change with the times, but not so flexible that it loses its effectiveness due to the foibles of individuals.

Finally, there remains a number of problems, such as the forms in which aid and encouragement may be provided, how best to draw on the ability and potential of the Institute, and many other associated problems. Some of these will have to be answered as time passes and experience is gained. Others can be foreseen and planned for in advance. The following program is an attempt to develop a satisfactory solution to some of the foreseeable problems without prejudicing freedom of action when the unforeseen occurs.

## Organization

It is proposed that the research organization consist of a Research Council and a series of ad hoc committees appointed by the President of the AIIE. The Director of Research would serve as Chairman of the Council, which would be an advisory body appointed by the President to provide guidance, assistance, and continuity in the direction of the research program of the AIIE. Each member of the Council would serve for a five-year period, and the membership would rotate. It should be possible to have represented on this body the breadth of knowledge necessary for a critical and thorough appraisal of the research program.

The two categories of research committees would serve two different purposes. One would be that of appraising and evaluating the state of development of specific areas of interest to industrial engineers—a function similar to that of the present research committees. On the basis of such committee reports, the direction of the overall program would develop. A second type of research committee

would be fewer in number and more functional in nature. Such committees would be charged with the detailed execution of the program outlined below. The turnover of membership of all committees would be faster than that of the Council, and these committees would operate more formally than in the past. As the Institute grows, if there is a desire for technical divisions of special interest, the present type of research committees would help form a basis for such divisions which could take over the specialty functions of such committees. Continuity of the overall program, however, will be assured by the Council and the Director of Research.

### A Program

Any program of research costs money. The problem in a young organization would appear to be the development of a program that costs little at the start but is capable of expansion to fill the needs that develop. It should also not fail to recognize those needs that are present at its inception, even if finances are limited. Obviously, such a program cannot furnish much financial sponsorship of research. It can, however, aid and encourage necessary financial support through other methods and also embody the means of developing sources outside the AIIE. Many foundations and some governmental agencies are already financing research in areas of interest to the industrial engineer and could not fail to consider information which indicated problems that need study. The following five-step program will demand a minimum expenditure in its early stages but could effectively spend a considerable amount when it becomes available.

The five areas of endeavor suggested are: (1) encouragement by prizes, (2) fellowship encouragement, (3) assistance through provision of information for better research coordination, (4) encouragement by direct support, and (5) encouragement and aid through supplementation of the AIIE publication medium. Each of these is discussed in detail.

Most professional and many technical organizations provide encouragement for research in the form of prizes. The proposal is to recognize outstanding work in the field with two objectives in mind. The first is the recognition of the individual and his accomplishment. The second is found in the educational advantage in such recognition. Other research personnel, graduate students, and engineers can benefit in a variety of ways from the availability of the information published. It is hoped, of course, that others will be encouraged to do research and that more people will learn to recognize good research.

Four types of prizes are contemplated. One is a prize for the best student paper. This would include a monetary reward and publication in some form. The second type is recognition of graduate study. A prize for each of the best master's essay and the best doctor's thesis is suggested. Both a certificate and some form of publication is suggested although the latter involves some considerable expenditure initially. The third type of prize is for faculty research at an academic institution and consists of a certificate and publication in the Journal. The fourth type is a prize for the best industrial research and also involves a certificate and publication. It may seem desirable to publish some of the papers in the Journal. In any event, another medium for publication of the longer papers or theses would be necessary. Details of all must be coordinated with other committees of the AIIE.

The graduate fellowship is a recognized method of encouraging young men to embark upon a career in research and also furnishes a method of aiding academic research. Many industrial firms provide such fellowships for selected fields of study. For the AIIE to be able to initiate such a program in the near future is unlikely because of the costs involved. But a program which encourages industrial firms to award special fellowships in the field of industrial engineering or to include industrial engineering among the fields open to fellowship candidates does not involve such a great financial expenditure and is also an effective way of accomplishing the same objectives.

A third method of aiding research is through the provision of information for better research coordination. This involves a number of activities, some of which have already been initiated by the existent research committees. It is not intended to infer more than the provision of more complete information for the various agencies active in research in areas of interest to industrial engineers. This activity should include at least three types of endeavor. One is the maintenance of satisfactory liaison with research agencies of other societies. A second is the historical review of research in special areas. The third, and perhaps most important, is the provision of a mechanism to provide information to interested research agencies and individuals about work being done on various topics and in various fields each year. Other organizations have special publications or media for the exchange of information on research taking place in various institutions. Publication of graduate thesis topics and abstracts each year would be an important aid in itself. Surveys which embrace not only academic institutions but other research sources would be quite helpful, and evidence exists that more information is desirable in order to avoid excessive duplication of effort in a field where all too little good research is taking place. The plan for the publication of the results and information obtained in this part of the program is outlined below in the fifth proposal.

A fourth method of encouraging research is by direct action to provide support. Of course, with a great deal of money and intelligent direction, such an activity is not so difficult. Without funds, however, more difficulties exist; but they are not insurmountable and some achievements should be possible even in the formative years of the organization. The underlying assumption to the success of such activity is that the committee involved has sufficient knowledge and prestige. It must have the knowledge to know what research is needed and how it fits the needs of the proposed sponsor. It must have the prestige to

make its recommendations significant. The functions would be, first, to develop industry, foundation, and government agency support, recognition, and relationships. A second function would be to assist in raising money for important research projects. A third function might be to act as a source of information for industry, governmental agencies, foundations, or research agencies interested in specific areas of research.

The final proposed method of aiding and encouraging research and also of promoting the interchange of ideas among members of the profession is the provision of a publication medium to supplement the Journal, a medium devoted to the publication of material which is unsuited for the Journal and which is of interest to those doing research. This publication would include research monographs too lengthy for the Journal, periodic surveys of research in industrial engineering, prize theses and papers too long for the Journal or not deemed of general interest, and bibliographical and abstract material. The field of industrial engineering needs such a publication, and there is no reason why it cannot ultimately become self-supporting, or nearly so. However, an initial expenditure for the first publications will be necessary. As these are sold to the membership and the general public, the funds recovered can be devoted to publication of additional monographs or reports.

### Conclusion

The above program may seem to be an ambitious one. If so, it is in keeping with the tone of the AIIE. It certainly cannot be accomplished overnight. It cannot be accomplished by one or a handful of individuals. It cannot be accomplished without funds. And it demands the participation of those members of the Institute who are familiar with research in the area and resources of both research talent and funds. There is no reason why the program cannot be initiated this year and brought to full stature next year. There is nothing sacred about the specific proposals made, and changes to incorporate other and better ideas should be made. But if something of this nature does not take place, it is dubious whether industrial engineering as a profession will ever realize its proper status.

# Another Approach to Machine Replacement Analysis

**By Roland W. Pinger**

*Lecturer, Mechanical Engineering Dept., College of Engineering, University of California*

Our profession should be grateful to R. O. Swalm for his fascinating problem in machine replacement analysis, which appeared in the Journal of Industrial Engineering for January 1955. As stated in his last sentence, we can no longer "look with complacency on dubious methods" of making decisions of this kind.

This does not mean, of course, that we must wholly agree with Professor Swalm's conclusions. Personally, I believe that his first three "approaches" give the right answer although the analyses may be "dubious," whereas the fourth "approach" gives the *wrong* answer because of an *incomplete* computation. By the latter I mean that the mere comparison of the total annual costs of two alternatives does not ordinarily supply a dependable criterion. *Most* new investments, replacement or otherwise, are intended to reduce cost, but the *real* question is whether that reduction is commensurate with the additional investment and risks involved.

### Modification of Approach

First of all, therefore, we should divide the annual saving, if any, by the *new* capital, to get an *annual rate of return* thereon. The adequacy of latter should then be judged in the light of pertaining or comparable risks. For example it is understood that one of our larger corporations, currently earning "$i$ %" on its old capital, will make a *new* investment only when "$R$," the predicted return thereon, exceeds 10%. The distinction between these rates is most important in our subsequent analysis. To use an analogy, "$i$" will hereafter refer to the dog himself, but "$R$" only to his *tail*. As everyone knows, the tail is usually happier than the basic anatomy.

More seriously, "$i$" will presently have the important function of determining the magnitude of the annual *depreciation* charge. Unless depreciation reserves are separately invested (they seldom are), they should be considered as earning at the same rate as any other *old* capital, namely "$i$%." In other words, annual depreciation expense will not be merely the total cost divided by "$n$," the years of use. It will be that cost divided by "$S_n$," a number always larger than "$n$," of the following name and formula:

$(i\%)S_n$ = Amount of an annuity of 1 for $n$ periods at $i$% per period.

$$= \frac{(1 + i)^n - 1}{i}$$

For example (5%) $S_{10}$ = 13.1808 in any good annuity table. A cost of $100 over ten years will be met by an annual depreciation charge, not of $10, but of 100 ÷ 13.18 or $7.59.

### Application to Swalm's "Table 1"

We may now *complete* Professor Swalm's "Table 1" in which the total *annual* costs are $1200 if the old asset is retained, but only $1100 if the new one is purchased. Obviously,

$$\text{"}R\text{"} = \frac{1200 - 1100}{4200 - 1800} = \frac{100}{2400} = .04\ 1/6$$

$$= 4\ 1/6\%\ \textit{per annum.}$$

If our predetermined minimum return on the new capital is 5%, it is quite evident that *we should not replace.*

It will be recalled, however, that for simplicity Professor Swalm used *straight-line* depreciation, which is equivalent to saying that the depreciation reserve earned nothing—at least for itself. Remembering what the hard-boiled master in the New Testament told the unfaithful servant, we might at least buy some good 3% bonds with the money, and thus make "*i*" equal 3% instead of nothing. Such action would make "Table 1" read as follows:

| Source of Expense | Cost Per Year if | |
|---|---|---|
| | Old asset is retained | New asset is purchased |
| Depreciation | $\frac{\$1800}{(3\%)S_6} = \frac{\$1800}{6.4684} = \$278$ | $\frac{\$4200}{(3\%)S_6} = \frac{\$4200}{6.4684} = \$649$ |
| Operating costs | $900 | $400 |
| Total annual costs | $1178 | $1049 |

"*R*" will then equal $\frac{1178 - 1049}{4200 - 1800} = \frac{129}{2400} = .05375 = 5\ 3/8\ \textit{Percent.}$

If our predetermined minimum return is still 5%, it now appears that we *might replace*, provided the risks are not incommensurate.

For a telephone, gas, or electric utility, we could say that 3% is easily earned by buying back some of its own bonds. Likewise the appropriate regulating commission, backed by numerous Supreme Court decisions, will usually adjust rates to earn about 5½ to 6% on the utility's "rate base." If, however, our company is just an ordinary industrial outfit, 5⅜% is *not enough*. So the answer to the replacement problem is still "*no.*"

### Application to Swalm's "Table 4"

Of course, Professor Swalm has anticipated our criticism by computing "Table 4" which differs from "Table 1" by the inclusion of 5% interest *as an expense*. This amounts to $52.50 if the old asset is kept, and $122.50 if the new asset is purchased, raising the total annual costs to $1252.50 and $1222.50 respectively. In this case

$$R = \frac{1252.50 - 1222.50}{4200 - 1800} \quad \frac{30}{2400} = .0125 = 1\tfrac{1}{4}\ \textit{Percent,}$$

If the 5% already inserted is viewed as *profit*, rather than as interest, it could, with some validity, be added to the 1¼% to produce a *total* return of 6¼% on the investment. This is considerably larger than the 5⅜% already computed, but it will be remembered that we *then* let the depreciation reserve earn only 3% instead of 5%.

Let us now assume that the company is currently earning 5% on its old capital, and that the depreciation reserve is therefore earning the same. This means using $S_n$ without apology, for if our industrial engineers aspire to professional status they had better not be afraid of an ordinary annuity table. "Table 4" will then look like this.

| Source of Expense | Cost Per Year if | |
|---|---|---|
| | Old asset is kept | New asset is purchased |
| *Capital Recovery* | | |
| Depreciation | $\frac{\$1800}{(5\%)S_6} = \frac{\$1800}{6.8019} = \$265$ | $\frac{\$4200}{(5\%)S_6} = \frac{\$4200}{6.8019} = \$618$ |
| Interest | $1800 × .05 = $90 | $4200 × .05 = $210 |
| Operating costs | $900 | $400 |
| Total annual costs | $1255 | $1228 |

$$\text{"}R\text{"} = \frac{1255 - 1228}{4200 - 1800} = \frac{27}{2400} = .01125 = 1\ 1/8\ \textit{Percent}$$

Adding the 5% as before, we get a *total* return of 6⅛% on the investment, which still means "*No*" to the replacement problem, if our company is an ordinary industrial one.

### The Dilemma And Its Solution

*This is most disappointing.* We industrial engineers really wish to throw out the old equipment, but have now found not three, but *four* reasons for *not* doing so. Is there not *some* "approach" which will give us the answer we desire, or at least tell us what factor has to be changed in order to *justify* replacement? The answer is "Yes," and without any mathematical skulduggery either.

The solution is to consider "*i*," "*R*" and "*X*" (value of old asset) all as *variables*, and to set up an equation (and possibly draw curves) to express the relationships envolved. Thus:

"*X*" = not just $1800, but whatever can be obtained for the old asset by a little judicious bargaining. Remember that the salesman is replacing his *new* asset by your *old* one.

"*i*" = not 3% or 5%, but whatever the depreciation reserve can be rightfully assumed to earn.

"*R*" = not 5% or 10%, but whatever can be considered a reasonable minimum return on new capital.

**"Table 5"**

We may now set up "*Table 5*" omitting interest as an expense, but expecting a correspondingly greater value for "*R*".

TABLE 5

| Source of Expense | Cost Per Year if | |
|---|---|---|
| | Old asset is kept | New asset is purchased |
| Depreciation | $\frac{X}{(i\%)S_6}$ | $\frac{\$4200}{(i\%)S_6}$ |
| Operating costs | \$900 | \$400 |
| Total annual costs | $\frac{X}{(i\%)S_6} + \$900$ | $\frac{\$4200}{(i\%)S_6} + \$400$ |

$$\text{"}R\text{"} = \frac{\frac{X}{(i\%)\,S_6} + 900 - \frac{4200}{(i\%)\,S_6} - 400}{4200 - X} = \frac{500}{4200 - X} - \frac{1}{(i\%)\,S_6}$$

From our table values for $S_6$ (amount of annuity of 1) may be obtained

| $i\%$ | $S_6$ |
|---|---|
| 0 | 6 |
| 5 | 6.8019 |
| 10 | 7.7156 |

Assuming that $X = 1800$ and $i = 0\%$,

$$R = \frac{500}{2400} - \frac{1}{6} = .2083 - .1667 = .0416$$

$$= 4\ 1/6\% \text{ as we found before.}$$

Likewise, if $X = 1800$ and $i = 5\%$

$$R = \frac{500}{2400} - \frac{1}{6.8019} = .2083 - .1470 = .0613$$

$$= 6\ 1/8\% \text{ as we found before.}$$

Finally, if $X = 1800$ and $i = 10\%$,

$$R = \frac{500}{2400} - \frac{1}{7.7156} = .2083 - .1296 = .0787 = 7.87\%$$

Similar computations can be made for other values of "*X*" (2200, 2000, 1600, 1400, for example), and all plotted as *Figure 1*.

It is now evident that while the earnings of the depreciation reserve are important (but not easily controlled), "*X*" is a *very* significant factor and one which is susceptible to *bargaining*. The new equipment salesman may have to *sell* at a list price, but there is probably no fixed limit to what he can offer for your *old* asset.

In any event, we need only tell him that we expect to earn say *5% on our depreciation reserve*, and *10% on any new capital*, and that this means that he must give us \$2176 for our old equipment if he wants to do business with us. If he will not or cannot do so, we must say "Farewell," for it is obvious that replacement is *not economical* either for him or for *us*.

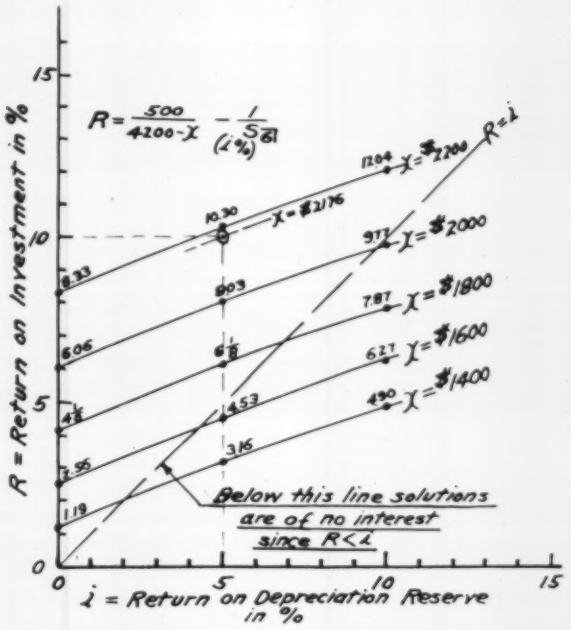


FIG. 1. Return on Investment for Various Salvage Values and Depreciation Reserve Earning Rates.

**Conclusion**

*In conclusion* we might draw a 45° line from the origin on Figure 1. *Below* that locus ($R = i$) we have little concern, for if our company is already earning a certain rate on its existing investment, it is not likely to accept *less* return on any new capital. We dislike dogs whose tails are sadder than their eyes.


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***Send resume to* Department A**
**Journal of Industrial Engineering,**
**225 North Avenue, N.W., Atlanta, Georgia**

# INSTITUTE INTERESTS*

## MEMBERSHIP REPORT

A recent report received from National Headquarters shows an increase of 275 members of A.I.I.E. and 41 affiliates during the period May 2, 1955 to August 1, 1955. If the same rate continues, over a thousand new members will be joining us annually. There are approximately two hundred membership applications being processed at present. This clearly demonstrates the continued activity of the Chapters in reaching the Industrial Engineers in their area and obtaining their interest in a professional organization.

During the same period only thirty members were dropped from the membership files. Some of those removed from the files were a result of continued return of mail addressed to them. Members changing address should insure that National Headquarters is notified.

The following membership figures are quoted as of October 1st:

| | |
|---|---|
| Senior members | 1189 |
| Associate members | 2249 |
| Total | 3438 |
| Affiliates | 193 |
| Grand total | 3631 |

Student membership figures will be published later in the fall.

## LOUISVILLE CHAPTER

Stephen Derry of the Louisville Chapter writes to us concerning the activities planned in the Louisville Area during the coming year.

The first event arranged is a Technical Societies Conference Evening Dinner Meeting on November 16, 1955. This is to be a joint meeting with all Technical Societies Chapters who are members of the Louisville Engineer & Scientist Technical Society Group, some 25 in all. It is to be a dinner meeting at the Kentucky Hotel. The speaker will be Mel Salveson of the General Electric Company, New York City. Mel formerly lived in Louisville and has many friends in that area. The subject of his talk will be "The Industrial Engineer on Management's Team." It will be treated broadly to cover other fields of engineering on Management's Top Policy Team.

The second event is still in the planning stages but it is certain to attract national interest. It is a Regional Conference scheduled for March 8–9, 1956. The conference theme will be "How Instruments and Electronics Are Changing the Field of Industrial Engineering within Industry." It is planned to combine the conference with the newly created Instruments and Electronics Traveling Show which opens in Pittsburgh on March 4 and will be in Louisville on March 7. This show will carry national publicity and members in other areas interested in its itinerary may contact Mr. Richard Rimbach, 845 Ridge Ave., Pittsburgh 12, Pennsylvania.

Present planning for the conference include one afternoon session, an all day session, two lunches and a dinner. Tom Potter is arranging for the speakers, and it is hoped that some of the National Officers will be present. Firm plans will be announced later in Institute Interests.

## PENINSULA CHAPTER

Mr. John D. Van Amringe, Technical Assistant to the Plant Manager of the Ford Division, Ford Motor Company, Milpitas, Calif. gave an excellent talk at the August meeting on the Production control and scheduling problem in this new plant.

The September meeting consisted of a tour of the Sunnyvale plant of Libby, McNeill and Libby. The plant was in full production at the time of our visit.

A "ladies' night" meeting will be held at the Villa Chartier Restaurant in San Mateo, Calif. on October 11, 1955.

The Peninsula Chapter is making good progress in its work as co-sponsor, along with the San Francisco-Oakland Chapter, of the Second Annual Western Regional Conference (AIIE) to be held in the Spring of 1956. The theme of the Conference will be: "Industrial Engineered Standards in Business".

Membership at last count (August 1955) stood at 72 people.

It has come to our attention that the "Handbook of Industrial Engineering" by W. Grant Ireson and Eugene L. Grant, both of Stanford University, is now available. Mr. Ireson is a member of the Peninsula Chapter AIIE.

## METROPOLITAN NEW YORK CHAPTER

The following is an outline of the activities planned by the Metropolitan New York Chapter for the 1955–56 season.

*General Meetings*

| Date | Topic | Speaker |
|---|---|---|
| Sept. 19 | How a Supplemental Unemployment Benefit Plan Affects Production Planning | Frank C. McCoard, Director of Production Planning and Control, Ford Motor Company |
| Oct. 24 | Wage Incentives | Ed Slagle, National President, AIIE |
| Nov. 28 | Are Your Standards Right for Cost Control? | Phil Carroll, Consulting Engineer |
| Dec. 19 | Automatic Data Processing | Dr. Samuel Alexander, Bureau of Standards |
| Jan. 23 | A New Concept of the Staff Function | Peter Drucker, Author, Lecturer, Consultant |
| Feb. 27 | Adapting for Automation | Auren Uris, Author, Editor, Research Institute of America |
| Mar. 19 | Management Controls Mean Action | Arnold Emch, Partner Booz, Allen & Hamilton |
| Apr. 23 | Operations Research Case Studies in Inventory Control & Production Scheduling | Wilfred Hugli, Coordinator of Plans & Research, Stevens Institute of Technology |
| May 28 | Reclamation of a Dying Management | Speaker to be announced |

The general meetings will be held at the National Cash Register Auditorium, 50 Rockefeller Plaza, New York City, at 7:45 P.M.

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* *Institute Interests* is a new section of the Journal designed to serve A.I.I.E. members in the same manner as the quarterly *Newsletter* which ceased publication in June. It is hoped that, in addition to Chapter News and reports from National Headquarters, space limitations will allow coverage of items of professional interest to all Journal readers.

A memorandum concerning public relation policies in respect to this section of the Journal has been mailed to all National Chapters. Further copies for individual members are available upon request. All news items and suggestions concerning content of this section of your Journal should be mailed to: N. K. Rogers, Associate Editor, Journal of Industrial Engineering, 225 North Avenue, N.W., Atlanta, Georgia.

*Special Technique Courses*

Cost Control Realistics
Automatic Data Processing (to be offered in March 1956)

*Inspection Trips*

Fall Trip: Nov. 5, 1955; Brookhaven Laboratories
Spring Trip: To be announced

*Seminars*

Engineering Economics and Cost Control
Linear Programming Applications
Organization and Management Control

The three seminars will be conducted by the Research & Education Division of the Metropolitan New York Chapter this season. These seminars are small, informal discussion groups dealing with areas of special interest in Industrial Engineering. Participants are invited to submit problems or cases from their own experience, which are analyzed and discussed under the guidance of chairmen experienced in the field. The three seminars, each meeting once a month, are described below.

The *Engineering Economics and Cost Control Seminar* under the guidance of J. I. Weindling will meet on Tuesdays starting October 4. This group will be concerned with finding practical solutions to monetary phases of engineering problems presented by its members and with problems of cost determination, allocation, and control. Discussion of two recent papers on equipment replacement and risk analysis, and formulation of plans for the seminar's 1955–1956 program are planned for the first session.

The second seminar on *Linear Programming Applications* will be conducted by Kurt Schaffir. Linear programming, a new and powerful mathematical technique, is finding increasing application in scheduling and selection of economic production programs. Through analysis of case studies provided by participants, seminar members will learn to recognize situations where L.P. can be applied advantageously. Training in the mathematical aspects of L.P., although helpful, is not essential for attendance of this seminar. This group will meet on Thursdays, starting October 20.

The *Organization and Management Control Seminar*, sponsored in conjunction with S.A.M., will be continued this year under the joint chairmanship of Don Rudkin and Robert C. Courboin. This group plans to give more attention this year to problems of management controls as applied to purchasing, public relations, personnel, costs, etc. Case studies will be used and analyzed to determine objectives, control procedures used, standards for comparison, and methods of appraising results. Meetings will be on Thursdays, starting October 13.

If you are interested in attending any of these discussion groups starting this fall, please telephone or drop a note right now to the respective chairman (addresses given below). All seminars are free to AIIE members. The Industrial Economics and Linear Programming groups will meet at the ARMCO offices in the Chrysler Building; the Management Control Seminar will meet at S.A.M. headquarters (5th Ave. and 14th St.).

A. *Engineering Economics and Cost Control*

J. I. Weindling, P.E.
Assistant Chief Engineer
The Korfund Co., Inc.
48-15 32nd Place
Long Island City 1, N. Y.
RAvenswood 9-7800

B. *Linear Programming Applications*

K. H. Schaffir
Mgr. Production Analysis Dept.
Merck & Co., Inc.
Rahway, New Jersey
RAhway 7-1200, Ext. 684

C. *Organization and Management Control*

D. A. Rudkin
Mgr. Organization Planning Dept.
Merck & Co., Inc.
Rahway, New Jersey
RAhway 7-1200, Ext. 3004

## ATLANTA CHAPTER

Dedicated to increased and more efficient industrial production through engineering, the members of the Atlanta Chapter of the AIIE have selected from among some of the area's outstanding companies their new officers and directors to carry out the organization's program for 1955–1956.

Serving as president is Frank J. Johnson, manager of Buildings Engineering, Lockheed Aircraft Corporation, Marietta, Ga. Winfield A. Brooks, Professor of Industrial Engineering at Georgia Tech, is first vice president, and William P. Biggers, Jr., Industrial Engineer, Southern Spring Bed Company, is second vice president.

Carrying out the duties of secretary is D. M. Pitts, and the treasurer is William R. Parks, both Industrial Engineers at Lockheed Aircraft Corp.

The new directors are James T. French, President, Southeastern Engineering and Mfg. Co.; George W. Morris, President, George W. Morris & Associates; James B. Roberts, Industrial Engineer, Ford Motor Company; and Leslie F. Zsuffa, Consulting Engineer and Director of Public Relations at Georgia Tech.

## CINCINNATI CHAPTER

The Cincinnati Chapter went off to a fast start with their first fall meeting on September 21st, at the Engineering Society headquarters.

Mr. Harry M. Hopkins, Vice President of the Tool Steel Gear and Pinion Company, spoke on "Industry In Turkey" and showed colored slides of his trip as a member of the E.C.A. productivity team.

Since this was the first meeting the following Officers and Committee Chairmen were introduced to the members and the visitors:

| | |
|---|---|
| President | Norman V. Gomes |
| Vice President | John D. Malone |
| Secretary | Richard Dister |
| Treasurer | Harry E. Placke |
| Director | Richard Forberg |
| Director | Lawrence Jackson |
| Director | Robert J. Topits |
| Director | S. H. Raskin |
| Placement | William B. Grimes |
| Program | John D. Malone |
| Publications | John Biddle |
| Reception | Alan Harding |
| Membership | Robert J. Topits |
| Conference Arrangements | Lawrence Jackson<br>S. H. Raskin |

The Cincinnati Chapter extends a standing invitation to all members to attend the meetings held the third Wednesday of each month at 6:30 in the Engineering Society Headquarters located at 1349 East McMillan St. If in town call Garfield 1-0800 and we will be glad to provide any additional information on the meetings, chapter doings, or places to go.

## E. C. KEACHIE

It is pleasant to note that E. C. Keachie of the Mechanical Engineering Department of the University of California in Berkeley has accepted a Fulbright award and will be guest professor at the Technische Hochschule, Darmstadt, Germany, during this academic year. While quite a few members of the Institute found themselves returning from European vacations during September,

Mr. Keachie and his family sailed on the America from New York on September 29th for a year's sabbatical.

Mr. Keachie serves the Institute as Chairman of the Research Committee on Terminology and is a member of the Editorial Board of the Journal.

### ALLISON C. NEFF

An appeal to the Nation's publishers to help stimulate interest in high school mathematics and science courses has been made by the president of the National Society of Professional Engineers.

In a letter to approximately 800 publishers of daily newspapers, Allison C. Neff, of Middletown, Ohio, newly installed president of the 36,000-member engineering group, asked the help of the press as a first step to "stem the tide of students away from elementary mathematics, physics and chemistry."

Mr. Neff, vice-president of Armco Drainage & Metal Products, Inc., asked that the publishers consider these facts:

1. Only about 25 per cent of our high school students now study algebra.
2. Only about 12 per cent of our high school students now study geometry.
3. There are many small and even some large high schools which offer no courses in the physical sciences.

"With America entering the first phase of the so-called atomic age we find ourselves in the amazing position of having a declining percentage of high school students enrolled in such basic courses as elementary algebra, and plane and solid geometry." Mr. Neff said.

He further pointed out that "without a high school background in elementary mathematics, a young person entering college is severely handicapped, and often all but blocked, in the pursuit of a career in engineering."

Mr. Neff suggested that the daily newspapers ask these questions: "Are there high schools in this community where students cannot get the background necessary for college work in engineering? Do high school counselors in this community attempt to stimulate an interest in training for a career in engineering? Is the number of high school students enrolled in algebra and geometry decreasing in this community?"

Mr. Neff stated that many recent studies by educational and governmental agencies indicate that the decline in high school enrollment in elementary math courses is increasing despite the fact that opportunities in the various engineering fields are abundant.

"The future course of American industrial achievement and national defense will be largely dependent on the engineering skills which can be developed from the generation now in high school," Mr. Neff added.

*(News of the Engineering Profession)*

### DR. M. R. LOHMANN

As was anticipated after the impending retirement, effective September 1st, of Dean Edward R. Stapley was announced, Dr. M. R. Lohmann has been appointed to the position at Oklahoma A. & M. College.

"Pete" Lohmann, an industrial and business expert, has been on the Engineering staff at A. & M. for 14 years and has served as Vice Dean for the past seven years. At the age of forty years, he will be one of the youngest men in the nation to head the Engineering Department of one of the major schools.

A native of Minnesota, Lohmann received his B.S. in Mechanical Engineering from the University of Minnesota in 1937 and M.S. from the University of Pittsburgh in 1941. He was awarded his Ph.D. from the University of Iowa only last year.

He was on the staff of Pennsylvania University before coming to Oklahoma A. & M. in 1941. He had also been with Aluminum Company of America, as an Industrial Engineer, for a time before joining the A. & M. staff.

As an Industrial Engineer, Lohmann helped conduct post-war conferences on Industrial Engineering in Norway and Sweden in 1950. He has also served as a special consultant to oil, gas, chemical and business firms in Oklahoma, Kansas, and Texas.

He is a Director in the Oklahoma Society of Professional Engineers, a Council member in the American Society for Engineering Education and holds membership in a number of other technical and professional engineering organizations.

Lohmann is married and has three children.

Congratulations and best wishes are extended by all members of A.I.I.E.

*(Oklahoma Professional Engineer)*

### WASHINGTON UNIVERSITY

The University College and the Department of Industrial Engineering of Washington University with the St. Louis chapters of the American Society for Quality Control, the American Institute of Industrial Engineers, and the Society for the Advancement of Management presented an intensive course in Statistical Quality Control during the period September 8 through September 16, 1955.

The course covered the following list of subjects of interest to the Industrial Engineer:

- Interpretation of $\bar{X}$ & R chart
- Relationship between process limits and specifications
- Getting and maintaining control of a process
- Special applications of variables control charts
- Construction and use of chart for fraction defective
- The chart for number defective
- Charts for number of defects per unit inspected
- Economic factors in use of quality control
- Principles of acceptance sampling
- Use of Dodge-Romig Tables
- Use of Mil-Std 105A
- Analysis of various sampling plans
- Sampling by variables and the place of quality control in a company
- Starting a quality control program

The objectives of this course were the preparation of the students for the application and administration of quality control in their own industry. Prerequisites included high school graduation or the equivalent.

The staff of instructors included:

Irving W. Burr. Professor Burr is in charge of the Statistical Laboratory at Purdue University as well as professor of mathematics. He is the author of the recent book "Engineering Statistics and Quality Control" as well as numerous articles in technical journals.

John A. Henry. Professor Henry teaches in the Mechanical Engineering Department at the University of Illinois. He has offered a regular course in Quality Control during the last ten years.

Donald J. Kaufman. Professor Kaufman is in the Industrial Engineering Department at Washington University. He was the course director for this intensive course.

Joseph Movshin. Mr. Movshin is Quality Control Director for the Ramsey Corporation of St. Louis. He was associated with the U. S. Air Force procurement office. He is president of the St. Louis section of ASQC.

Mason E. Wescott. Professor Wescott is Chairman of the Editorial Board of ASQC and editor of *Industrial Quality Control*. He teaches in the Mathematics Department of Rutgers University.

### UNIVERSITY OF MISSISSIPPI

A ten day short course on statistical quality control at the University of Mississippi offered Southern industrial personnel

an opportunity to study this vital aspect of production under the guidance of some of the nation's foremost experts.

The course, held September 12–24, was planned by Dr. Gayle McElrath, Professor of Industrial Management of the University of Minnesota. Instructors included Professor McElrath; Mr. Harmon Bayer, Quality Control Consultant, Detroit; and Mr. Arthur Bender, President of the American Society of Quality Control. In addition, industry speakers were invited from the major areas to be represented by registrants: wood fibers, metals, textiles, chemicals, and electrical appliances.

This short course was designed to offer enrollees an opportunity to learn the basic concepts of Statistical Quality Control; analyze and interpret in-plant data; discuss administrative problems with representatives from industry; broaden their concept of the use of statistical methods; and evaluate new material as it applies to their own company operations.

The course was sponsored by the Mississippi Manufacturers Association and the University of Mississippi.

### WESTERN RESERVE UNIVERSITY

Western Reserve University will be host at a three-day conference on "Practical Utilization of Recorded Knowledge—Present and Future," to be held Jan. 16–18, 1956, on the WRU campus in Cleveland, Ohio.

Emphasis will be on organization and use of printed material in such areas as the sciences, law, patents, military and government information, business, industry and education.

Offering the conference will be Western Reserve's School of Library Science and its new Center for Documentation and Communication Research. Dr. Jesse H. Shera is dean of the library school; director and associate director, respectively, of the Center are James W. Perry and Allen Kent. The conference will follow the Jan. 15 dedication of WRU's new $1,600,000 library.

More than 30 experts will be on the three-day program, including:

Russell Ackoff, chief of operations research group, Case Institute of Technology; Norman Ball, interdepartmental committee for scientific research and development, National Science Foundation; Walter Crafts, associate director of research, Electro Metallurgical Co.; Hugh W. Field, vice president, Atlantic Refining Co.; H. R. J. Grosch, manager AGT-Computations, General Electric Co.; Herman H. Henkle, librarian, John Crerar Library; Louis Koenig, vice president, Southwest Research Institute; William N. Locke, head of the modern languages department, Massachusetts Institute of Technology; James Mack, librarian, Lehigh University; and Ralph R. Shaw, professor at the Graduate School of Library Service, Rutgers University.

Complete information on the conference is available from the Dean, School of Library Science, Western Reserve University, Cleveland 6, Ohio.

### UNIVERSITY OF CALIFORNIA (LOS ANGELES)

Beginning September 26, University of California Extension will offer seventeen weekly lecture sessions on Natural Resources. Sponsored by the Engineering Department, the lectures will be given on Mondays, from 7–9:30 in Room 2276 of the Chemistry Building on the Los Angeles campus.

Directed towards management, engineers, and others with an active or potential interest in resources, the lectures will discuss water, air, land, and other resource problems of vital concern to California and its future. The reclamation of fresh water from the sea, air pollution, patterns of material and energy use, and nuclear and solar energy, all will be included as subjects which will appeal to nearly all engineers whether engaged directly with resource projects or not.

Speakers will include Harrison Brown of California Institute of Technology who will deliver the September 26 lecture on "Natural and Human Resources" and R. R. Revelle, of the University's Institute of Oceanography at La Jolla who will talk on October 3 about marine resources.

Ensuing speakers at sessions through January 30, 1956, are Martin R. Huberty, A. F. Bush, R. F. Logan, A. F. Pillsbury, Karl C. Hamner, Robert M. Glendinning and Louis B. Slichter, all of U.C.L.A.; E. D. Howe, Hans Jenny, John A. Zivnuska, Siegfried V. Wantrup and A. Starker Leopold, all of Berkeley; Emil Mrak and Frederick A. Brooks of Davis; Chancy Starr, North American Aviation; W. P. Taylor, Claremont, and J. L. Fisher, Resources for the Future.

Bulletins with complete course and registration information are available on request to offices of Engineering Extension at U.C.L.A.

To contribute to the development of engineers and managers and to prepare them for higher management responsibilities, University of California Extension and the College of Engineering and School of Business Administration on the Los Angeles campus of the University will offer an Engineering and Management course from January 23 to February 2, 1956.

Inaugurated at U.C.L.A. last January, the program, first of its kind to offer instruction in both the traditional and the new areas of industrial engineering and management theory and practice, brought executives, managers and supervisors, from firms throughout the United States, Canada and the Hawaiian Islands to the Los Angeles campus.

The ten-day, 8 a.m. to 5 p.m. course, will include twenty offerings covering General Management Subjects, Traditional Industrial Engineering, and New Principles and New Techniques such as automation and electronic data processing for business and industry, according to Edward P. Coleman, coordinator. Early applications for admission this year indicate that the number of applicants will exceed 125, the total number which will be admitted.

Each participant may choose a program tailored to his own needs to improve his current job performance, prepare him for a new assignment, or supplement his company's training program, the coordinator points out.

Information folders and application blanks are available on request to Mr. Coleman at the College of Engineering, University of California, Los Angeles 24, California.

### SCIENCE CONGRESS IN NUCLEAR ENGINEERING

For those Industrial Engineers who are getting in on the ground floor of Nuclear Engineering, the Science Congress in that subject being held in Cleveland, December 12–16, should be of great value. This conference will be coordinated by the Engineers Joint Council for 26 engineering and scientific groups, A.I.I.E. being among them. It will be the largest and most important conference of its kind ever staged in the United States.

Over two hundred and ninety papers will be presented by leading nuclear authorities from sixteen universities, thirteen government laboratories, and thirty four industrial corporations. These papers will be grouped into 50 sessions running concurrently covering latest developments in nearly every phase of industry, science, and medicine.

Some of the sessions of interest to the Industrial Engineer are:

- Safety and Site Selection for Reactors (6 papers)
- Instrumentation for Reactors (6 papers)
- Reactor Control and Instrumentation (6 papers)
- Economics in Reactor Design (6 papers)
- Legal and Insurance Problems (6 papers)
- Educational Requirements for Nuclear Engineering (6 papers)
- Reviews of Literature in Atomic Energy Fields (6 papers)
- Dissolution and Chemical Processing (5 papers)

Complete information concerning advance registration may be obtained by writing: Engineers Joint Council, 29 West 39th Street, New York 18, N. Y.

## ENGINEERING COMPENSATION

Engineers and other professional employees in American industry now are earning about 4.5 per cent more than they earned last year, according to a survey of compensation paid to administrative and technical personnel just completed by the Executive Compensation Service of the American Management Association. The majority of the companies surveyed reported granting salary increases to individuals in this group during the past year.

The study, the second on this subject that the 21,000-member management educational association has conducted, covered 20 engineering and professional job categories in 19 industries. It is part of a continuing series designed to report salary ranges for specific "exempt" (from compulsory overtime penalty pay provisions of the Fair Labor Standards Act) jobs in business and industry. Most of the positions studied are technical or highly specialized in nature; typical are those of development chemist, project engineer (electrical or mechanical), industrial engineer, and sales engineer.

Considering the great demand for and short supply of professional personnel, the range of salaries reported in the survey is surprisingly narrow, the A.M.A. report says. The average beginning engineer receives about $4,500 a year. Median pay for industrial engineering positions is approximately $6,000 annually; for chemical positions, $6,500; for electrical and mechanical engineering, $7,000.

The pay level for these 20 administrative and technical positions is just about the same as that of production foremen, as indicated by a recent A.M.A. survey of foreman compensation. Like foremen and like "middle management" personnel (those between first-line supervision and the policy-making level), individuals in similar professional and administrative positions tend to receive similar salaries regardless of geographic location. In contrast to management compensation, which usually is higher in larger companies, their salaries do not vary significantly among industries or with company size, the study indicates.

Technical and professional employees are less likely to receive bonuses in addition to their salaries than are foremen and middle management personnel. Only a fifth of the individuals included in the new survey received bonuses this year, as compared to a fourth of the foremen and two fifths of the middle management executives.

Like the other reports of the A.M.A.'s Executive Compensation Service, the administrative and technical positions surveys are designed to help companies evaluate their compensation policies in the light of current practice in other firms. These confidential studies are available on a subscription basis to business and industrial executives who have responsibility for administration of the compensation involved.

*(American Management Association News*

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# RECENT READABLES

## AUTOMATION

"Automation Dictionary", C. L. Peterson, *Advanced Management*, Pg. 30, July 1955.

A list of definitions of the terms commonly used by the Automatic Control Engineer. The definitions are written in very simple terms.

"So You Want to be an Automation Expert", E. A. Murphy, *Electronics Digest*, Pg. 47, July, 1955.

An excellent parody of a typical Automation Dictionary. Examples: Closed Loop—the path described by an inebriated man in a revolving door. Digital Computor—A guy who counts on his fingers. Feedback—What happens to your money when you play Poker with the gang. Operations Research—A surgeon looking for a lost sponge, etc.

EDITOR'S NOTE: I couldn't resist including the last one.

"Machine Works From Memory", Editor, *Plant Engineering*, Pg. 102, July 1955.

A report on a new electronic device which permits intricate machined, low tolerance work pieces on multi-axis machines completely controlled by magnetic tape, on which entire work cycles have been numerically programmed. The development of the machine resulted from three years of research by MIT and General Electric.

## COST REDUCTION

"Information Feedback to Management and Employees", F. C. Claassen, R. H. Schroeder, E. C. Reid, and T. R. Wolf, *Advanced Management*, Pg. 11, August 1955.

A series of five papers discussing cost reduction and control through information feedback. Actual applications of the feedback principle to a variety of specific situations in a number of companies are reported. Feedback to both Management and Employees is discussed on such situations as assembling, downtime, machining, and maintenance.

"Anybody Can Cut Overhead Costs", Phil Carroll, *Factory Management & Maintenance*, April 1955.

The author discusses the dangers in incorrectly analyzing and distributing overhead costs. To quote: "We carry out labor and material costs to the fourth decimal place. But we spread on the overhead with a shovel." The author suggests three directions that efforts should take in solving problem. (1) Overhead time should not be put in productive standards. (2) Acute analysis of overhead operations. (3) Analysis of all overhead expenses as they are related to all products. Recognition that most overhead costs do not apply equally to all products.

"Maximum Product Value at Minimum Cost", C. W. Bryant, *Advanced Management*, Pg. 14, July 1955.

The author reports on the Value Analysis Technique used by General Electric to stimulate creative thinking directed toward cost reduction. The Value Analysis job plan consists of the following: (1) The Information Phase where all facts and not opinions are obtained concerning function, cost, quantity, vendor, and drawings; (2) the Speculative Phase in which every possible solution is proposed; (3) the Analytical Phase in which the dollar value of each idea is determined; (4) the Program Planning Phase in which the job is broken into small parts and specialists are assigned to each; (5) the Program Execution Phase in which the best ideas are pursued to a conclusion; (6) the Suggestion Sheet Phase in which the recom-

mended action is turned over to another department for follow up and prompt action.

### ENGINEERING ECONOMY

"How to Build a Sound Equipment Policy", G. J. Matchett, *Iron Age*, Pg. 205, August 25, 1955.

Describes the Do's and Don'ts of cost analysis as a prerequisite to a sound equipment policy. A case history is utilized to explain the use of the MAPI formula. A chart for determining the "Adverse Minimum" is utilized in the case history. The author outlines the company departmental sources that should be used in developing the proper cost data.

### INVENTORY CONTROL

"How Much to Reorder When", E. K. Hedrick, *Factory Management & Maintenance*, Pg. 110, August 1955.

The biggest problem with most inventory reorder formulas is that reorder quantities are only correct when production requirements and parts delivery schedules remain fairly constant. Reynolds Aluminum has solved this problem by using a flexible-order-point system. This system involves three control factors: (1) Estimate of actual usage as compared with normal usage, (2) normal and maximum delivery times, (3) degree of protection against shortages required at the time.

### MATERIALS HANDLING

"Retooling for Materials Handling", J. R. Bright, *Advanced Management*, Pg. 17, July 1955.

The author suggests an overall company handling review leading to the establishment of a centralized material handling authority. Significant trends in handling devices are discussed along with the Mechanization Profile Chart. This chart was developed by the author to assist in analyzing existing and proposed procedures and to reveal indications of the degree of automaticity in various mechanical sequences.

"What to Consider When Selecting or Installing Overhead Handling Systems", R. W. Roberts, *Plant Engineering*, Pg. 99, July 1955.

Emphasis on the importance of preplanning the design of overhead handling systems. Outlines the planning of a system and includes the general factors to consider in selecting one of the following three systems: (1) Separate, individual overhead handling system in each area, department or bay, (2) one interlocked system covering the entire plant; and (3) one interlocked system covering several areas plus independent systems in isolated areas.

"New High in Warehousing", Editor, *Factory Management & Maintenance*, Pg. 60, August 1955.

Describes the benefits derived from the installation of automatically controlled conveyors and palletizers in a large warehouse. The new handling system takes as many as 48,000 cases of H. J. Heinz product from product lines during an 8-hour shift and delivers them on pallets to conveyor terminals.

"Materials: Smart Handling Pays", K. W. Bennett, *Iron Age*, Pg. 56, May 26, 1955.

A report on the Sixth National Materials Handling Exposition at Chicago. Discusses some of the problems solved by manufacturers through improved handling devices. Monorail systems, outside vertical conveyors, radio communication on lift trucks, vacuum lifting devices, remote controlled tractors and mobile cranes are some of the devices discussed.

### PRODUCTION CONTROL

"Production Control Setup Helps Keep Shipments on Schedule", C. W. Buler, *Iron Age*, Pg. 95, May 26, 1955.

Outlines a production control system developed for a plant which does not produce stock items, but instead turns out a wide variety of parts on a made-to-order basis. This system fulfils three basic requirements: (1) Details every operation to be performed on a piece of material; (2) specifies on a master control form the completion date of each operation; and (3) identifies the exact location of material in process at any given time.

### QUALITY CONTROL

"Some Challenging Questions in Quality Control", E. G. Olds, *Industrial Quality Control*, Pg. 5, July 1955.

This is the talk given by the author in accepting the 1954 Shewhart Medal. Mr. Olds discusses the questions that have arisen in the twenty-four years he has been concerned with quality control. These questions, the author states, fall into four categories: Philosophical, Technical, Educational, and Organizational.

"The Rule of IQC in Today's Chemical Company", M. S. Renner, *Industrial Quality Control*, Pg. 7, July 1955.

This discusses some of the reasons why people have trouble getting started using statistics, indicates a way to make a beginning and discusses problems of specification and testing precision in the chemical industry. A basis for communication between the Quality Control Man and the Chemist; i.e., a common language basis.

"Ultrasonic Transmission Tester Speeds, Simplifies Production Inspection", N. W. Shubring, *Iron Age*, Pg. 87, August 4, 1955.

Describes the use of ultrasonic tester developed by the General Motors Research Laboratories. The device evaluates the test piece by its ultrasonic conduction, giving a direct reading or rejection of the part. This non-destructive method required 1¼ hours for 1000 bolts, in one critical operation, whereas the previous method took 10 hours.

### SCHEDULING

"How to Get Manpower for Turnarounds", J. W. Towler, *The Oil & Gas Journal*, Pg. 119, July 11, 1955.

Describes the system used by the Union or Company for minimizing overall maintenance manpower costs by contractive manpower for peak workloads. The procedure involves the use of a combination of fixed company forces, semi-permanent contractor crews and variable contractor crews. The article outlines the organization, work planning, work scheduling and budget controls utilized.

### WAGE INCENTIVES

"Financial Incentives: The Flywheel of Management Planning", Phil Carroll, *Advanced Management*, Pg. 5, July 1955.

Mr. Carroll discusses incentives which he states are the foundation of sound management planning. Time standards as the backbone of planning become effective only when financial incentives are utilized to insure their attainment. "Incentives are the flywheel effect of man's interest since he has a financial share in making plans come true."

"Direct and Indirect Incentives", Phil Carroll, *Management Record*, June 1955.

The author presents a convincing argument for work standards and incentives. To quote Mr. Carroll, "Management must manage. And to do this it needs better cost data. Knowing material cost is not enough; but without work standards, that is all that is known about cost. Labor costs based on what you actually have paid for are after the fact and can be any amount." The author's comment on incentives can be summed up by one statement; "If work standards are used without incentives, wage costs may be higher by 20% to 35% and workers' earnings 25% to 35% less than they might be."

"New Look at Methods Incentives", W. W. Taylor, *Factory Management & Maintenance*, Pg. 90, August 1955.

The author advocates the use of methods rather than production incentives. His suggestion is a measured daywork

standard with no premium for meeting standard, and a high reward suggestion system to get methods improvement which workers normally keep to themselves for fear of rate resetting. Some interesting charts are presented by the author as proof that production incentives won't work as well as "methods incentives."

## WORK MEASUREMENT

"Management Integration Through Methods & Standards", T. E. Kelly, *Advanced Management*, Pg. 24, August 1955.

Using his own company's experience, the author indicates how methods and standards are a necessity in organization planning, cost reduction planning, communication, incentives, standard practices and forms control. The probable effectiveness of new management tools such as operations research, electronic computors, business data and facsimile transmission, and automatic devices are discussed.

"A New Look At Allowances", Editor, *Factory Management & Maintenance*, Pg. 112, August 1955.

This article describes the factors considered by a British manufacturer in determining proper job allowances. Their allowance formula includes elemental allowances for: (1) Personal time, (2) fatigue—physical exertion, (3) fatigue—working conditions, (4) unavoidable delays, and (5) a load factor which reduces the preceding allowances on jobs involving waiting time during machine paced operations.

"Standardized Maintenance Pays", F. O. Pierson, *Petroleum Processing*, Pg. 996, July 1955.

The result of Atlantic Refining's attempt at controlling and reducing maintenance costs through labor measurement, planning & scheduling. Outlines the function of the planners in devising weekly work schedules. Large turnarounds are planned and scheduled a year in advance. Through the use of this system, Atlantic Refining has been able to achieve reductions of from 20-25% in total man days of work during turnaround.

## BOOKS

*"Applied General Statistics"*, F. E. Croxton & D. J. Cowden, 2nd Edition, New York, Prentice-Hall, Inc.

This is the most widely used book on all phases of statistics available today. The basic statistical concepts are covered as well as statistical applications and techniques applicable to specialized fields. Series analysis, index numbers, tests of significance, analysis of variance and correlation are adequately treated.

*"Industrial Purchasing"*, J. H. Westing, J. V. Fine, and Members of the MAPI, New York, John Wiley & Sons, Inc., 1955, 421 pp, $7.50.

The authors have drawn on the experience of many years of purchasing activity to produce an excellent reference on the mechanics, theory, practices and organization of the purchasing function. Related activities such as traffic, speculation, and make-or-buy are also covered.

*"Depreciation"*, Eugene L. Grant & Paul T. Norton, Jr., Revised Printing, New York, The Ronald Press Co., 1955, 504 pp., $7.50.

By liberalizing the depreciation methods allowable for tax purposes, the U. S. Revenue Act of 1954 brought major changes in depreciation treatment for all purposes. The authors have explored not only the tax changes but also the financial and accounting implications and effects of the new law and its regulations.

*"The Computer Directory, 1955"*, The June Issue of Computers & Automation published by Berkeley Enterprizes, 36 West 11th St., New York 11, N. Y., 164 pgs., $4.00.

*Contents:* Part 1: Who's Who in the Computer Field—about 7500 entries. Part 2: Roster of Organizations in the Computer Field—about 300 entries. Part 3: The Computer Field: Products & Services for Sale—about 600 entries classified under 62 headings.

*"Management of Expanding Industries"*, W. H. Newman and J. P. Logan, New York, Columbia University Press, 1955, 125 pp., $2.75.

This volume is a report of a round table discussion by prominent executives on the problem of managing and controlling an organization as it grows from small to medium to large. It contains many useful comments on successful and unsuccessful business methods.

*"Wage & Salary Administration"*, D. W. Belcher, New York, Prentice-Hall, Inc., 1955, 490 pp, $9.00.

Control and administration of labor and salary costs is the avenue by which the author approaches wage and salary payments. Job evaluation, wage levels, payment methods, fringes, individual wage determination and the overall control of wages and salaries are covered.

*"Work Simplification,"* by Ben S. Graham, The Standard Register Co., Dayton 1, Ohio, 43 pages, free.

This publication is a compilation of a series of articles on Paperwork Simplification by Ben S. Graham. It presents the basic concepts of Work Simplification and carries these through to their application.

Mr. Graham is well known for his outstanding contribution in Paperwork Simplification. This is a subject of interest to all Industrial Engineers. Copies of the publication can be obtained without charge from Mr. Ben S. Graham, Director of Methods Research, Standard Register Co., Dayton 1, Ohio.

*The Compleat Strategyst*, by J. D. Williams, McGraw-Hill Book Co., Inc., New York, 1954, 234 pages.

This is one of the Rand Series, published by McGraw-Hill. It is a layman's presentation of the Theory of Games, and it is mighty fascinating. The presentation is excellent—very straight forward and interesting—actually a marvel of good expression. The author's objective is to present some of the fundamentals of Game Theory without the complexity of mathematical intricacies and to interest the reader in the possibilities of this analytical tool as a problem solver in his own work. I would strongly recommend this book to each and every Industrial Engineer. After you have read it, then you can progress to the more mathematical and theoretical treatments such as *"Introduction to Game Theory"* by J. McKinsey, McGraw-Hill Book Co., Inc., New York, 1952, 371 pages. This is a much more involved treatment of the same subject. Game Theory has some promise as a valuable tool for the advanced Industrial Engineer.

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*(AIIE Long Range Planning Committee, Industrial Engineering Seminar, Cornell University, October 20-21, 1955)*